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P. HODGES AND L. D. SMITH

TEST OF A THIRTY INCH SAMSON TURBINE

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TEST OF A THIRTY INCH SAMSON TURBINE

BY

PAUL HODGES

A Thesis Submitted for the Degree of

BACHELOR OF SCIENCE

GENERAL ENGINEERING COURSE

AND BY

LEATHEM DALEY SMITH

For the Degree of

BACHELOR OF SCIENCE

CIVIL ENGINEERING COURSE

UNIVERSITY OF WISCONSIN

1909

INTRODUCTION.

Tests on both a 30" Samson Turbine and an 18" Pelton Wheel were run in the Hydraulics Laboratory of the University of Wisconsin during the summer of 1908. Besides the two parties submitting this thesis there were two graduate engineers working on the same test for theses for a Master's degree, Wilfred C. Parker, U. W. '06 and Chas. I. Corp, an assistant professor in Kansas University. These composed the party on the test of the 30" Samson and with the exception of L. D. Smith for the test of the wheel also.

The careful test of any waterwheel or turbine is of great interest but such tests are difficult to make on installed plants. To run a test of any commercial value a well equipped laboratory is almost necessary, for the water flow must be regulated carefully and exactly. The wheel must be kept clear of sticks, etc., which would interfere with its temporary efficiency and an accurate weir and measuring apparatus must be installed and gauged. From this it can be seen that it is practically impossible to make any valuable test

of the great majority of wheels after they are installed for service, and that therefore a test made in the laboratory to determine the most efficient speeds, gate openings and working heads or more generally the value of the most efficient ϕ ($= \frac{\text{vel. of periphery of wheel}}{\text{vel. of water}}$) is of as great importance as the test of any other machine.

The laboratory in which these tests were run has complete equipment for work of this kind with an ever increasing variety of wheels and water measuring devices, and tests run here have proved to be of great importance in the study of the laws governing turbines, pumps and other hydraulic machinery.

* * *

Description of Apparatus.

The water was supplied by a 30" Morris Centrifugal Pump located in the northeast corner of the Laboratory, taking the water from a 10' canal leading directly to the lake. The pump delivered the water into a receiving basin of considerable size from which it flowed through a large channel into the wheel pit, a chamber 10' square directly over the tail-race. The draft tube is carried down into the tail-race below the level of the water, thus maintaining a good suction through the tube.

A flat wooden platform was built over the wheel resting on the bearings but not coming in contact with the shaft, to serve as an air shield and prevent a sucking away of the water over the wheel and thereby keeping the head uniform.

Figure 1 shows the Samson wheel complete - 30" in diameter, - manufactured by James Leffel & Co., of Springfield, O., - regulated by Wicket Gate System of control.

The water that will flow through a turbine cannot

be estimated accurately by measuring its pumping supply. A slight difference in the form of the buckets increases or lessens the velocity of the water through the wheel and makes more or less difference in the actual discharge. The quantity can be ascertained accurately only by measuring the water after leaving the wheel when in working operation. In this test the water was conducted away by the tail race and discharged over a weir 10' standard width. Tail race was 10' wide and 5' deep so that there was no appreciable velocity of approach. The head on the weir was measured by two hook gages one on either side, set in a still water basin connected with the tail race by a pipe which admitted the water about 10' above the weir.

Head and tail race gages and pipe connected to chambers, and all gages were placed at weir so that one man could get all readings simultaneously.

Actual Horse Power was measured by the common Prony brake method. When the single level gear was used the weight was directly transmitted from a vertical pulley by a brake to the scale, but when the test conducted without the gear the pulley was directly

keyed to the vertical turbine shaft and the horizontal pressure at the end of the brake arm was connected into a downward vertical pressure by a bell crank or arm. A scale was placed in a convenient position and the pressure accurately balanced. The zero correction, caused by the weight of the brake arm was taken care of by adding weights after which the actual weights added were read and used in the calculation.

The mechanical counter for reading revolutions was placed conveniently so that if necessary one man could attend to the brake, the weighing and the reading of the revolutions.

Method of Conducting Test.

No calibration test of the measuring weir was necessary as it had been calibrated by Mr. C. B. Stewart who found that the discharge conformed accurately to that calculated by Francis formula for flow over a sharp edged weir.

Before beginning the test the zero of the Hook gauges was set to coincide with the crest of the weir.

The head and tail race gages were set with respect to the same datum so that the difference between the two gage readings gave directly the head on the wheel.

A leakage test was made to determine if any water escaped from the head into the tail race without passing through the turbine and the amount was found to be negligible.

Before each run the turbine was inspected and all debris such as sticks and pieces of wood which had been carried through the pump into the wheel pit was removed. During test care was taken to keep the turbine bearings, brake pin and brake well oiled and to keep pulley cool by means of a jet of water. The head was kept as nearly constant as possible by throttling the engine; the proper height of the water being shown by a float in the channel connecting receiving chamber with the wheel pit.

The scale was kept balanced by loosening or tightening brake and the total revolutions were read from the mechanical counter every three minutes and the average R. P. M. computed.

The Test.

Readings were taken for a three fourth and full gate with gear in place under heads varying from three and one half to seven feet in first instance,and six and one half in the second,and the three fourth gate opening was repeated without gearing.

Each test for a certain gate opening and head was started with a load sufficient to keep the wheel at a standstill and then drop in each proportioned so as to give us 8-9 points on the curve - down to runaway speed when no load was forced on the wheel.

During each run readings were taken every three minutes of speed, elevation of water in head and tail race, and head on weir.

Three minutes was allowed to elapse after scale weight had been changed to allow head and tail gage and weir readings to adjust themselves and become constant. A sample page of readings will be found in the data. The data under any one head is an average of four readings usually obtained from the readings at different gate openings and at increments of load. As fast as

run the values were computed, a curve was plotted for K and K' curves and if point did not fall close to the general curve the run was repeated.

Results and Calculation.

The methods used in obtaining the data and calculating the results will be taken up in order of the headings. In all cases the readings taken for a given weight on the scales were averaged and the average value used in calculation.

True Scale Weight - was read directly as the zero correction did not enter into the calculation.
The revolution for three minutes were taken from the vertical turbine shaft by mechanical revolution counter and the result divided by three to obtain average R. P. M.

Head on weir - equal to average of two Hooke Gages.

Actual Head on wheel - equal to difference between head and tail race readings.

Discharge - taken from Table 111 of Watersupply and Irrigation Paper number 200 of U. S. G. S. which gives discharge per foot of crest for any head H. based

on Francis formula for the flow of water over a sharp edged weir.

$$Q = 3.33 \ L \ H \ 3/2$$

Q = discharge cubic feet per second.

L = 10 feet.

H = head on weir in feet.

Q = 33.3 H 3/2.

Actual Horse Power of wheel without gearing

$$= \frac{2\pi \ L \ N \ W}{33{,}000} \qquad (1)$$

where L equals length of lever arm in feet = 3.5

N = R P M of wheel

W = true scale weight in pounds.

Inserting values of L equation (1) reduces to

Actual H. P. = .000667 W N

$$\text{With gearing A.H.P.} = \frac{2\pi \ L \ W \ N \times 3/2}{33{,}000} \qquad (1')$$

the factor 3/2 enters for the gear ratio = $\frac{66}{44}$ that for every turn of the turbine the load went half again as far, so that equation (1) reduces to .001 W H.

$$\text{Theoretical H.P.} = \frac{Q \ H \ W}{550} \qquad (2)$$

Where Q = discharge in cubic feet per second

H = head on wheel in feet

W = weight of cubic foot of water = 62.5 lbs.

The above equation reduces to $.1136\ Q\ H$.

$$\text{Efficiency} = \frac{A.H.P.}{T.H.P.}$$

$\phi = \frac{V'}{V}$ where V' = velocity of periphery of runner in feet $= \frac{N \times 30 \times \pi}{12 \times 60}$

V = theoretical spouting velocity due to head.

$$V' = \frac{D \times \pi \times N}{12 \times 60} = .00437\ D\ N$$

where D = diameter of runner in inches

N = R P M

$V = 8.02 \times \sqrt{H}$ combining we have

$$\phi = \frac{3.1416\ D\ N}{720 \times 8.02 \times \sqrt{H}}$$

Since diameter is equal to 30 inches the equation becomes $.0163 \frac{N}{\sqrt{H}} = \phi$

$$K = \frac{.000668}{H} W$$

$$K' = \frac{E\sqrt{H}}{N}$$

Maximum efficiency obtained was 72% for 6' head with 7/8 gate and $\phi = .84$.

Maximum H. P. was 25.25 for $\frac{8}{8}$ gate and 7' head. Comparing efficiency curve of the turbine run with and without gear, the efficiency of the gear was found to be about 93%.

General equation for the power and efficiency curve were worked out with a three point formula and placed on the curve sheets.

At low heads our efficiencies came out higher in value for the runs with gear than without gear.

The efficiency curves for the full gate ran below the efficiency curves for the 3/4 gate both with and without gearing showing that the turbine was overgated at full gate, for greatest efficiency.

* * *

SUMMARY FOR FULL GATE AND WITH GEARING.

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H.P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{\frac{1}{4}}}$	ϕ
						6.5' Head.							
318	1.198	8.85	2.31	6.54	00	43.67	00	32.40	00.0	.0486	.0250	0.0	.00
250	1.294	8.82	2.44	6.38	95	49.02	23.74	35.60	66.7	.0392	.0178	37.5	.610
225	1.316	9.03	2.48	6.55	112	50.27	25.20	37.40	67.4	.0344	.0154	45.8	.714
200	1.307	8.78	2.47	6.31	118	49.76	23.60	35.70	66.2	.0317	.0141	47.0	.768
175	1.330	9.02	2.50	6.52	143	51.08	25.00	37.83	66.1	.0268	.0118	56.0	.912
150	1.327	8.96	2.49	6.47	155	50.90	23.20	37.40	62.0	.0232	.0102	60.9	.995
125	1.308	8.81	2.47	6.34	159	49.81	19.90	35.92	55.4	.0197	.0088	63.1	1.03
100	1.292	9.09	2.45	6.54	170	48.90	17.00	36.34	46.8	.0153	.0071	66.5	1.08
75	1.257	9.15	2.40	6.75	178	46.93	13.35	36.00	37.1	.0111	.0054	68.5	1.12
50	1.220	8.88	2.37	6.51	183	44.87	9.15	33.20	27.5	.0077	.0038	71.7	1.18
25	1.215	8.89	2.35	6.54	196	44.60	4.90	33.14	14.8	.0038	.0019	76.7	1.25
0	1.204	8.84	2.33	6.51	207	43.99	00	32.48	0.0	.0000	.0000	81.2	1.33
						6.0' Head.							
297	1.173	8.37	2.30	6.07	00	42.31	00	29.20	0.0	.0490	.0251	00	.00
225	1.268	8.38	2.41	5.97	95	47.55	21.40	32.30	66.2	.0377	.0171	38.9	.633
200	1.275	8.36	2.42	5.94	106	47.94	21.20	32.40	65.4	.0337	.0151	43.4	.710
175	1.284	8.35	2.44	5.91	124	48.45	21.70	32.50	66.9	.0296	.0131	51.0	.840
150	1.288	8.33	2.44	5.89	141	48.68	21.15	32.60	64.8	.0255	.0111	58.1	.950
125	1.286	8.36	2.45	5.91	153	48.56	19.10	32.60	58.6	.0212	.0093	63.0	1.030
100	1.252	8.41	2.40	6.01	159	46.65	15.90	31.85	50.0	.0166	.0077	64.9	1.06
75	1.219	8.46	2.36	6.10	167	44.82	12.54	31.08	40.40	.0123	.0060	67.6	1.11
50	1.205	8.51	2.32	6.19	178	44.05	8.90	31.00	28.70	.0081	.0040	71.4	1.16
25	1.192	8.48	2.33	6.15	189	43.34	4.72	30.30	15.56	.0041	.0020	76.2	1.25
00	1.186	8.55	2.31	6.24	201	43.01	0.00	30.60	0.00	.00	.00	80.4	1.31

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM.	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ø
5.5' Head.													
280	1.136	7.75	2.26	5.49	00	40.32	.00	25.10	0.0	.0510	.0261	0.0	.00
220	1.248	7.95	2.40	5.55	82	46.43	18.00	29.20	61.6	.0396	.0177	34.9	.567
195	1.264	7.92	2.42	5.50	105	47.32	20.50	29.70	69.0	.0354	.0154	44.7	.728
165	1.273	7.88	2.43	5.45	126	47.83	20.80	29.60	70.3	.0302	.0130	54.0	.882
140	1.274	7.86	2.43	5.43	140	47.86	19.60	29.5	66.5	.0258	.0110	60.2	.978
115	1.264	7.88	2.41	5.47	151	47.32	17.40	29.4	59.3	.0210	.0092	64.5	1.06
90	1.209	7.86	2.36	5.50	156	44.27	14.00	27.6	50.8	.0163	.0076	66.5	1.10
70	1.193	7.82	2.34	5.48	163	43.39	11.40	27.20	42.0	.0128	.0060	69.7	1.14
50	1.183	7.82	2.32	5.50	172	42.85	8.60	26.80	32.1	.0091	.0044	73.4	1.20
25	1.172	7.86	2.32	5.54	185	42.25	4.63	26.60	17.4	.0045	.0022	78.4	1.28
00	1.160	7.79	2.29	5.50	196	41.60	0.0	26.00	0.0	.00	.00	83.6	1.44
5.0' Head.													
265	1.113	7.30	2.25	5.05	00	39.10	0.0	22.40	0.0	.0525	.0265	0.0	.00
200	1.204	7.37	2.34	5.03	77	43.99	15.40	25.10	61.3	.0397	.0178	34.4	.561
175	1.218	7.30	2.36	4.94	99	44.76	17.30	25.20	68.7	.0354	.0154	44.5	.725
150	1.228	7.32	2.38	4.94	121	45.29	18.20	25.40	71.6	.0304	.0131	54.5	.889
125	1.232	7.38	2.38	5.00	135	45.54	16.90	25.90	65.2	.0250	.0108	60.5	.990
100	1.216	7.38	2.37	5.01	145	44.62	14.50	25.40	57.2	.0200	.0088	64.8	1.06
75	1.162	7.30	2.30	5.00	150	41.68	11.2	23.6	47.8	.0150	.0071	67.2	1.10
50	1.153	7.34	2.29	5.05	161	41.23	8.05	23.7	33.9	.0099	.0047	71.9	1.17
25	1.139	7.35	2.27	5.08	174	40.48	4.40	23.3	18.9	.0049	.0024	77.3	1.26
00	1.123	7.22	2.24	4.98	187	39.63	0.0	22.2	0.0	.00	.00	83.8	1.36

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
						4.5' Head.							
233	1.070	6.69	2.19	4.50	00	36.83	0.0	18.8	0.0	.0518	.0263	0.0	.00
175	1.164	6.79	2.30	4.49	76	41.82	13.3	21.4	62.1	.0390	.0173	35.9	.585
150	1.180	6.77	2.32	4.45	99	42.68	14.8	21.6	68.5	.0336	.0146	47.0	.770
125	1.188	6.77	2.33	4.44	121	43.12	15.1	21.8	69.2	.0281	.0120	57.4	.940
100	1.185	6.79	2.33	4.46	134	42.96	13.4	21.8	61.5	.0224	.0097	63.5	1.04
75	1.129	6.79	2.25	4.54	137	39.95	10.3	20.6	50.0	.0165	.0078	64.3	1.05
50	1.111	6.76	2.24	4.52	149	39.00	7.45	20.0	37.2	.0111	.0053	70.2	1.15
25	1.093	6.77	2.28	4.55	161	38.05	4.02	19.7	20.4	.0056	.0027	75.8	1.23
						4.0' Head.							
235	1.032	6.15	2.15	4.00	00	34.91	0.0	15.82	0.0	.0588	.0296	0.0	.00
160	1.106	6.22	2.23	3.99	58	38.73	9.27	17.5	53.0	.0401	.0182	29.0	.475
135	1.137	6.24	2.27	3.97	93	40.37	12.55	18.2	69.0	.0341	.0148	46.7	.763
110	1.153	6.29	2.29	4.00	114	41.23	12.53	18.7	66.9	.0275	.0117	57.0	.930
85	1.145	6.24	2.28	3.96	126	40.80	10.70	18.4	58.1	.0214	.0092	63.4	1.03
60	1.087	6.18	2.21	3.97	132	37.74	7.92	17.0	46.5	.0151	.0070	66.4	1.08
45	1.081	6.21	2.20	4.01	141	27.43	6.35	17.1	37.2	.0112	.0053	70.5	1.14
30	1.072	6.21	2.19	4.02	149	36.96	4.46	16.89	26.4	.0075	.0035	74.5	1.21
15	1.052	6.14	2.16	3.98	155	35.93	2.32	16.21	14.3	.0038	.0018	77.7	1.27
00	1.052	6.17	2.16	4.01	164	35.93	0.0	16.32	0.0	.00	.00	82.0	1.33

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
3.5' Head.													
187	.983	5.57	2.08	3.49	00	32.43	0.0	12.87	0.0	.0536	.0272	0.0	.00
130	1.084	5.76	2.20	3.56	73	37.55	7.50	15.19	62.6	.0365	.0162	38.7	.63
115	1.090	5.72	2.22	3.50	86	37.87	9.89	15.08	65.5	.0329	.0142	46.0	.75
100	1.099	5.75	2.22	3.53	100	38.37	10.00	15.36	65.1	.0283	.0122	53.3	.87
85	1.079	5.71	2.20	3.51	107	37.30	9.10	14.89	61.1	.0242	.0107	57.2	.94
70	1.059	5.67	2.17	3.50	112	36.29	7.83	14.43	54.2	.0200	.0090	60.0	.98
55	1.032	5.67	2.14	3.53	119	34.89	6.55	14.00	46.8	.0156	.0074	63.4	1.03
40	1.027	5.72	2.14	3.58	128	34.66	5.12	14.1	36.3	.0112	.0054	67.7	1.10
25	1.015	5.75	2.12	3.63	137	34.02	3.43	14.0	24.3	.0069	.0034	71.9	1.17
00	.993	5.65	2.09	3.56	149	32.95	0.0	13.35	0.0	.00	.00	79.0	1.29

* * *

SUMMARY FOR THREE FOURTHS GATE AND WITH GEARING.

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ø
						7.0' Head.							
320	1.099	9.19	2.21	6.98	00	38.36	0.0	30.5	0.0	.0459	.0278	0.0	.00
235	1.193	9.38	2.34	7.04	103	43.39	24.2	35.1	68.8	.0334	.0177	39.0	.63
200	1.199	9.30	2.34	6.96	129	43.71	25.8	34.6	74.6	.0288	.0153	48.7	.80
175	1.193	9.32	2.33	6.99	140	43.39	24.5	34.4	71.3	.0250	.0134	53.0	.86
150	1.167	9.37	2.31	7.06	147	41.98	22.1	33.7	65.5	.0212	.0118	55.3	.90
125	1.159	9.36	2.30	7.06	160	41.55	20.0	33.4	59.8	.0177	.0099	60.2	.98
100	1.144	9.32	2.27	7.05	172	40.74	17.2	32.6	52.7	.0142	.0082	64.7	1.05
75	1.135	9.31	2.26	7.05	184	40.26	13.8	32.3	42.8	.0106	.0062	69.2	1.13
50	1.127	9.30	2.26	7.04	197	39.84	9.85	31.9	30.9	.0071	.0042	74.3	1.21
25	1.120	9.31	2.24	7.07	209	39.47	5.23	31.7	16.5	.0035	.0021	78.8	1.29
00	1.108	9.28	2.22	7.06	223	38.84	0.0	31.2	0.0	.00	.00	84.1	1.37
						6.5' Head.							
220	1.073	8.70	2.18	6.52	98	41.19	21.6	30.6	68.3	.0338	.0178	38.4	.63
200	1.164	8.78	2.30	6.48	109	41.79	21.8	30.8	70.8	.0308	.0165	42.8	.70
180	1.168	8.78	2.30	6.48	123	42.04	22.2	31.0	71.5	.0278	.0148	48.2	.79
160	1.157	8.79	2.28	6.51	132	41.42	21.2	30.7	68.9	.0246	.0133	51.7	.83
140	1.131	8.83	2.26	6.47	138	40.02	19.3	29.4	65.6	.0216	.0121	54.4	.89
100	1.114	8.82	2.23	6.59	158	39.15	15.8	29.4	53.8	.0152	.0088	61.5	1.01
80	1.110	8.84	2.22	6.62	169	38.94	13.5	29.3	46.1	.0121	.0070	65.7	1.07
50	1.091	8.70	2.20	6.50	185	37.92	9.25	28.1	33.0	.0077	.0046	72.5	1.19
25	1.087	8.73	2.19	6.54	200	37.71	5.00	28.0	17.8	.0038	.0023	78.2	1.28
00	1.080	8.76	2.19	6.57	212	37.38	0.0	37.9	0.0	.00	.00	82.6	1.35

SUMMARY FOR THREE FOURTHS GATE AND WITH GEARING.

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
						7.0' Head.							
320	1.099	9.19	2.21	6.98	00	38.36	0.0	30.5	0.0	.0459	.0278	0.0	.00
235	1.193	9.38	2.34	7.04	103	43.39	24.2	35.1	68.8	.0334	.0177	39.0	.63
200	1.199	9.30	2.34	6.96	129	43.71	25.8	34.6	74.6	.0288	.0153	48.7	.80
175	1.193	9.32	2.33	6.99	140	43.39	24.5	34.4	71.3	.0250	.0134	53.0	.86
150	1.167	9.37	2.31	7.06	147	41.98	22.1	33.7	65.5	.0212	.0118	55.3	.90
125	1.159	9.36	2.30	7.06	160	41.55	20.0	33.4	59.8	.0177	.0099	60.2	.98
100	1.144	9.32	2.27	7.05	172	40.74	17.2	32.6	52.7	.0142	.0082	64.7	1.05
75	1.135	9.31	2.26	7.05	184	40.26	13.8	32.3	42.8	.0106	.0062	69.2	1.13
50	1.127	9.30	2.26	7.04	197	39.84	9.85	31.9	30.9	.0071	.0042	74.3	1.21
25	1.120	9.31	2.24	7.07	209	39.47	5.25	31.7	16.5	.0035	.0021	78.8	1.29
00	1.108	9.28	2.22	7.06	223	38.84	0.0	31.2	0.0	.00	.00	84.1	1.37
						6.5' Head.							
220	1.073	8.70	2.18	6.52	98	41.19	21.6	30.6	68.3	.0338	.0178	38.4	.63
200	1.164	8.78	2.30	6.48	109	41.79	21.8	30.8	70.8	.0308	.0165	42.8	.70
180	1.168	8.78	2.30	6.48	123	42.04	22.2	31.0	71.5	.0278	.0148	48.2	.79
160	1.157	8.79	2.28	6.51	132	41.42	21.2	30.7	68.9	.0246	.0133	51.7	.83
140	1.131	8.83	2.26	6.47	138	40.02	19.3	29.4	65.6	.0216	.0121	54.4	.89
100	1.114	8.82	2.23	6.59	158	39.15	15.8	29.4	53.8	.0152	.0088	61.5	1.01
80	1.110	8.84	2.22	6.62	169	38.94	13.5	29.3	46.1	.0121	.0070	65.7	1.07
50	1.091	8.70	2.20	6.50	185	37.92	9.25	28.1	33.0	.0077	.0046	72.5	1.19
25	1.087	8.73	2.19	6.54	200	37.71	5.00	28.0	17.8	.0038	.0023	78.2	1.28
00	1.080	8.76	2.19	6.57	212	37.38	0.0	37.9	0.0	.00	.00	82.6	1.35

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
6.0' Head.													
277	1.055	8.25	2.16	6.09	00	36.09	0.0	25.0	0.0	.0454	.0273	0.0	.00
210	1.133	8.25	2.26	5.99	96	40.16	20.2	27.4	73.8	.0351	.0188	39.2	.644
175	1.142	8.29	2.27	6.02	114	40.64	20.0	27.8	71.9	.0291	.0154	46.6	.755
150	1.137	8.27	2.26	6.01	128	40.37	19.2	27.5	69.8	.0250	.0134	52.2	.854
125	1.109	8.31	2.24	6.07	136	38.89	17.0	26.8	63.3	.0206	.0115	57.1	.899
100	1.100	8.30	2.23	6.07	149	38.42	14.9	26.5	56.2	.0165	.0093	60.6	.985
75	1.090	8.32	2.21	6.11	162	37.89	12.2	26.3	46.4	.0123	.0071	65.6	1.07
50	1.081	8.34	2.20	6.14	178	37.43	8.9	26.1	34.1	.0081	.0048	71.8	1.17
25	1.071	8.34	2.19	6.15	193	36.91	4.83	25.8	18.7	.0041	.0024	77.8	1.27
00	1.060	8.33	2.17	6.16	207	36.34	0.0	25.4	0.0	.00	.00	83.5	1.36
5.5' Head.													
249	1.020	7.65	2.12	5.53	00	34.30	0.0	21.6	0.0	.0450	.0272	0.0	.00
195	1.100	7.75	2.22	5.53	99	38.42	19.3	24.2	79.6	.0352	.0189	42.1	.688
175	1.104	7.76	2.22	5.54	102	38.63	17.8	24.3	73.3	.0316	.0170	43.2	.71
150	1.110	7.75	2.23	5.52	118	38.94	17.7	24.4	72.5	.0272	.0144	50.2	.82
125	1.091	7.78	2.22	5.56	126	37.95	15.7	24.0	65.4	.0225	.0122	53.5	.873
100	1.072	7.78	2.18	5.60	140	36.96	14.0	23.5	59.5	.0179	.0101	59.2	.964
75	1.053	7.67	2.16	5.51	150	35.98	11.3	22.6	50.0	.0136	.0078	63.8	1.04
50	1.044	7.69	2.14	5.55	164	35.52	8.2	22.4	36.6	.0090	.0053	69.6	1.14
25	1.036	7.66	2.14	5.52	179	35.11	4.47	22.0	20.3	.0045	.0027	76.1	1.24
00	1.024	7.65	2.13	5.52	195	34.51	0.0	21.6	0.0	.00	.00	83.0	1.35

5.0' Head.

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
225	.991	7.19	2.10	5.09	00	32.85	0.0	19.05	0.0	.0442	.0267	0.0	.00
160	1.071	7.18	2.20	4.98	92	36.91	14.7	20.9	70.4	.0321	.0171	41.2	.674
140	1.066	7.09	2.18	4.91	107	36.65	15.0	20.4	73.5	.0285	.0152	48.3	.786
120	1.067	7.24	2.18	5.06	120	36.70	14.4	21.2	67.8	.0237	.0127	53.4	.867
100	1.037	7.14	2.14	5.00	125	35.16	12.5	20.0	62.5	.0200	.0112	55.9	.916
75	1.023	7.18	2.13	5.05	141	34.45	10.6	19.8	53.5	.0148	.0085	62.8	1.03
50	1.013	7.20	2.12	5.08	155	33.95	7.74	19.6	39.5	.0099	.0057	68.8	1.12
25	.994	7.03	2.09	4.94	165	33.00	4.12	18.5	22.3	.0051	.0030	74.2	1.21
00	.985	7.05	2.07	4.98	182	32.55	0.0	18.4	0.0	.00	.00	81.6	1.33

4.5' Head.

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
205	.953	6.58	2.05	4.53	00	30.98	0.0	15.9	0.0	.0453	.0274	0.0	.00
140	1.037	6.64	2.15	4.49	90	35.16	12.6	17.9	70.4	.0312	.0166	42.5	.695
120	1.033	6.65	2.14	4.51	105	34.96	12.6	17.7	71.1	.0266	.0144	49.5	.810
100	1.025	6.66	2.14	4.52	114	34.56	11.4	17.8	64.1	.0221	.0119	53.8	.880
75	.999	6.67	2.10	4.57	125	33.25	9.38	17.3	54.3	.0166	.0093	58.4	.956
50	.983	6.71	2.09	4.62	142	32.45	7.11	17.1	41.7	.0108	.0063	66.3	1.08
25	.964	6.53	2.05	4.48	155	31.52	3.88	16.1	24.2	.0056	.0033	73.1	1.20
00	.958	6.57	2.05	4.52	173	31.22	0.0	16.1	0.0	.00	.00	81.4	1.33

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
4.0' Head.													
182	.909	6.00	2.00	4.00	00	28.86	0.0	13.3	0.0	.0455	.0276	0.0	.00
130	.981	6.11	2.08	4.03	70	32.35	9.1	14.8	61.4	.0322	.0176	34.8	.57
110	.981	6.09	2.08	4.01	86	32.36	9.5	14.7	64.3	.0275	.0149	43.0	.696
90	.966	6.08	2.06	4.02	97	31.62	8.73	14.4	60.4	.0224	.0125	48.3	.790
75	.955	6.10	2.05	4.05	106	31.08	7.95	14.3	55.7	.0185	.0105	52.8	.863
60	.944	6.14	2.04	4.10	117	30.54	7.72	14.2	49.3	.0146	.0085	57.8	.945
45	.927	6.06	2.03	4.03	128	29.72	5.8	13.6	42.3	.0112	.0066	63.8	1.04
15	.919	6.07	2.01	4.06	150	29.34	2.25	13.5	16.6	.0037	.0022	74.4	1.21
00	.919	6.05	2.01	4.04	161	29.34	0.0	13.48	0.0	.00	.00	80.2	1.31
3.5' Head.													
190	.866	5.50	1.95	3.55	00	26.84	0.0	10.8	0.0	.0535	.0332	0.0	.00
90	.936	5.54	2.03	3.51	85	30.16	7.5	12.0	62.0	.0256	.0140	44.3	.727
80	.917	5.57	2.01	3.56	88	29.24	7.0	11.9	59.0	.0224	.0126	46.7	.763
65	.910	5.61	2.00	3.61	97	28.91	6.3	11.9	53.2	.0180	.0104	51.1	.835
50	.891	5.49	1.98	3.51	107	28.01	5.4	11.2	57.8	.0142	.0084	57.2	.935
15	.876	5.52	1.97	3.55	136	27.30	2.0	11.0	18.5	.0042	.0026	72.2	1.18
00	.874	5.53	1.97	3.56	148	27.21	0.0	11.0	0.0	.00	.00	78.7	1.28

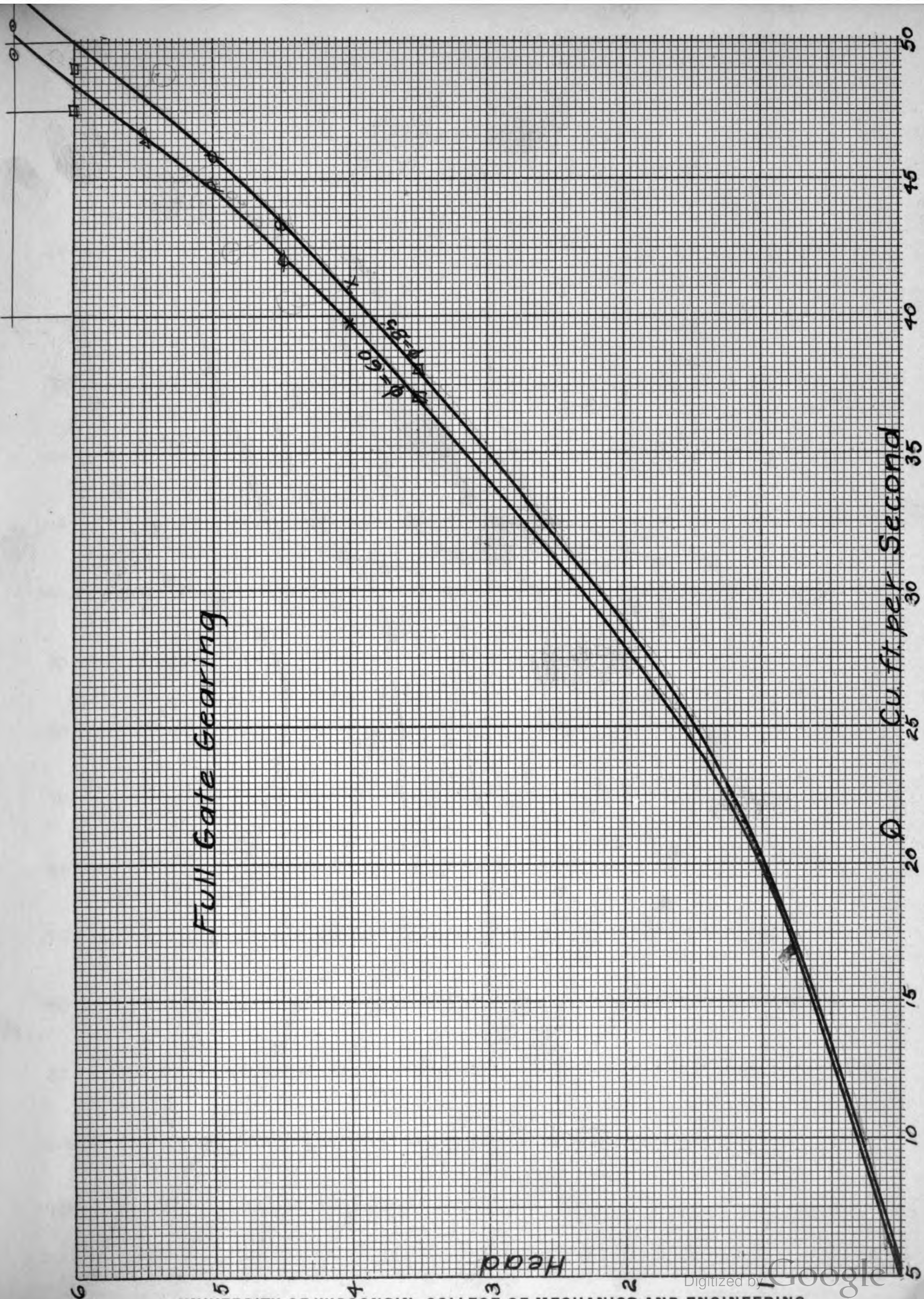
SUMMARY FOR THREE FOURTHS GATE AND NO GEARING.

Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
7.0' Head.													
390	1.170	9.29	2.30	6.99	72	42.14	18.7	31.0	60.4	.0372	.0222	27.2	.45
330	1.192	9.29	2.32	6.97	113	43.34	24.9	34.3	72.7	.0316	.0170	42.9	.70
270	1.187	9.17	2.31	6.86	138	43.07	24.8	33.6	73.9	.0263	.0140	52.7	.86
210	1.156	9.29	2.29	7.00	154	41.39	21.6	32.9	65.7	.0200	.0113	58.2	.95
150	1.143	9.28	2.28	7.00	173	40.69	17.3	32.4	53.5	.0143	.0082	65.4	1.06
90	1.125	9.26	2.24	7.02	194	39.74	11.6	31.7	36.6	.0086	.0050	73.3	1.19
00	1.113	9.25	2.25	7.00	226	39.10	0.0	31.1	0.0	.00	.00	85.6	1.40
6.5' Head.													
455	1.083	8.82	2.20	6.62	00	37.53	0.0	28.2	0.0	.0460	.0277	0.0	.00
350	1.155	8.76	2.29	6.47	84	41.34	19.6	30.4	34.5	.0360	.0195	33.1	.54
300	1.169	8.72	2.32	6.40	116	42.09	23.2	30.6	75.8	.0313	.0165	45.8	.75
250	1.161	8.72	2.30	6.42	133	41.66	22.2	30.4	73.0	.0260	.0139	52.5	.86
200	1.136	8.77	2.27	6.50	147	40.32	19.6	29.8	66.0	.0205	.0115	57.5	.94
150	1.121	8.78	2.26	6.52	164	39.52	16.4	29.3	56.0	.0154	.0087	64.3	1.05
100	1.111	8.79	2.24	6.55	182	39.00	12.1	29.0	42.0	.0102	.0057	71.2	1.16
50	1.101	8.79	2.23	6.56	200	38.47	6.7	28.7	23.2	.0051	.0030	78.2	1.28
00	1.086	8.73	2.21	6.52	217	37.69	0.0	27.9	0.0	.00	.00	85.0	1.39

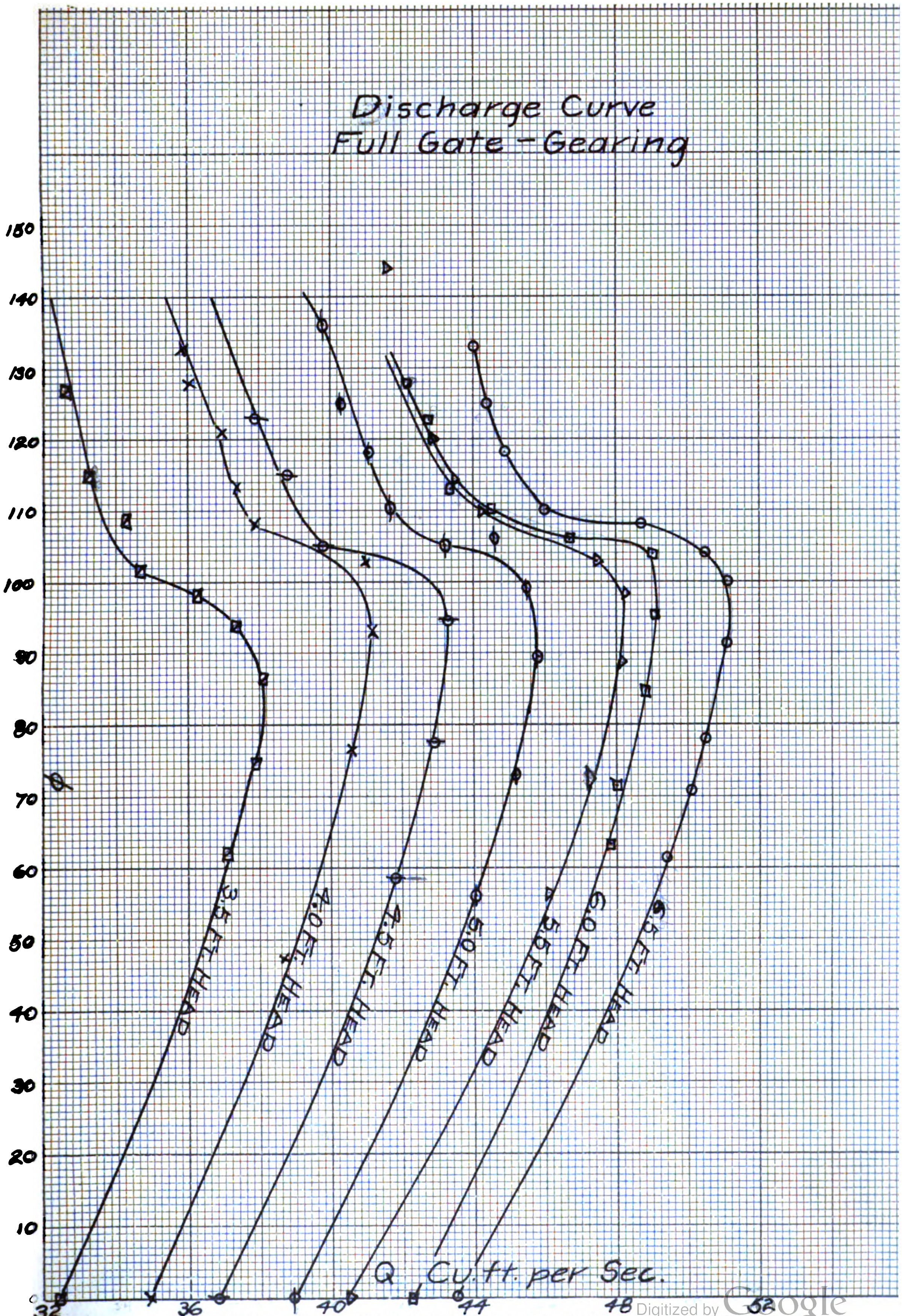
Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
						6.0' Head.							
413	1.061	8.38	2.18	6.20	00	36.39	0.0	25.6	0.0	.0444	.0267	0.0	.00
310	1.133	8.33	2.26	6.07	86	40.16	17.8	27.7	64.3	.0340	.0184	34.9	.57
270	1.147	8.31	2.28	6.03	113	40.91	20.3	28.0	72.6	.0299	.0158	46.0	.75
230	1.144	8.32	2.27	6.05	129	40.75	19.8	28.0	70.7	.0254	.0135	52.5	.86
190	1.117	8.32	2.24	6.08	140	39.21	17.7	27.2	65.4	.0208	.0115	56.8	.93
150	1.101	8.34	2.22	6.12	155	38.47	15.5	26.8	58.0	.0164	.0093	62.7	1.03
110	1.093	8.35	2.20	6.15	168	38.05	12.3	26.6	46.4	.0119	.0068	67.8	1.11
70	1.081	8.33	2.20	6.13	185	37.43	8.6	26.1	33.1	.0076	.0044	74.7	1.22
40	1.079	8.33	2.19	6.14	197	37.32	5.3	26.0	20.2	.0044	.0025	79.5	1.30
00	1.062	8.28	2.17	6.11	221	36.44	0.0	25.3	0.0	.00	.00	85.3	1.39
						5.5' Head.							
400	1.021	7.66	2.12	5.54	00	34.35	0.0	21.66	0.0	.0482	.0291	0.0	.00
300	1.080	7.68	2.19	5.49	56	37.37	11.2	23.3	48.1	.0364	.0201	23.9	.39
265	1.105	7.72	2.23	5.49	93	38.68	16.4	24.1	68.3	.0322	.0172	39.7	.649
230	1.110	7.68	2.24	5.44	114	38.94	17.5	24.1	72.6	.0283	.0149	48.9	.80
195	1.103	7.76	2.23	5.53	126	38.57	16.3	24.3	67.3	.0235	.0125	53.6	.87
150	1.071	7.66	2.18	5.48	139	36.91	13.9	23.0	60.41	.0183	.0102	59.4	.97
100	1.056	7.68	2.15	5.53	156	16.14	10.4	22.7	45.9	.0121	.0069	66.2	1.08
70	1.049	7.70	2.15	5.55	169	35.78	7.3	22.6	35.0	.0084	.0049	71.8	1.17
40	1.044	7.70	2.15	5.55	181	35.52	4.04	22.4	21.6	.0048	.0028	76.9	1.25
00	1.027	7.64	2.13	5.51	200	34.66	0.0	21.7	0.0	.00	.00	85.2	1.39

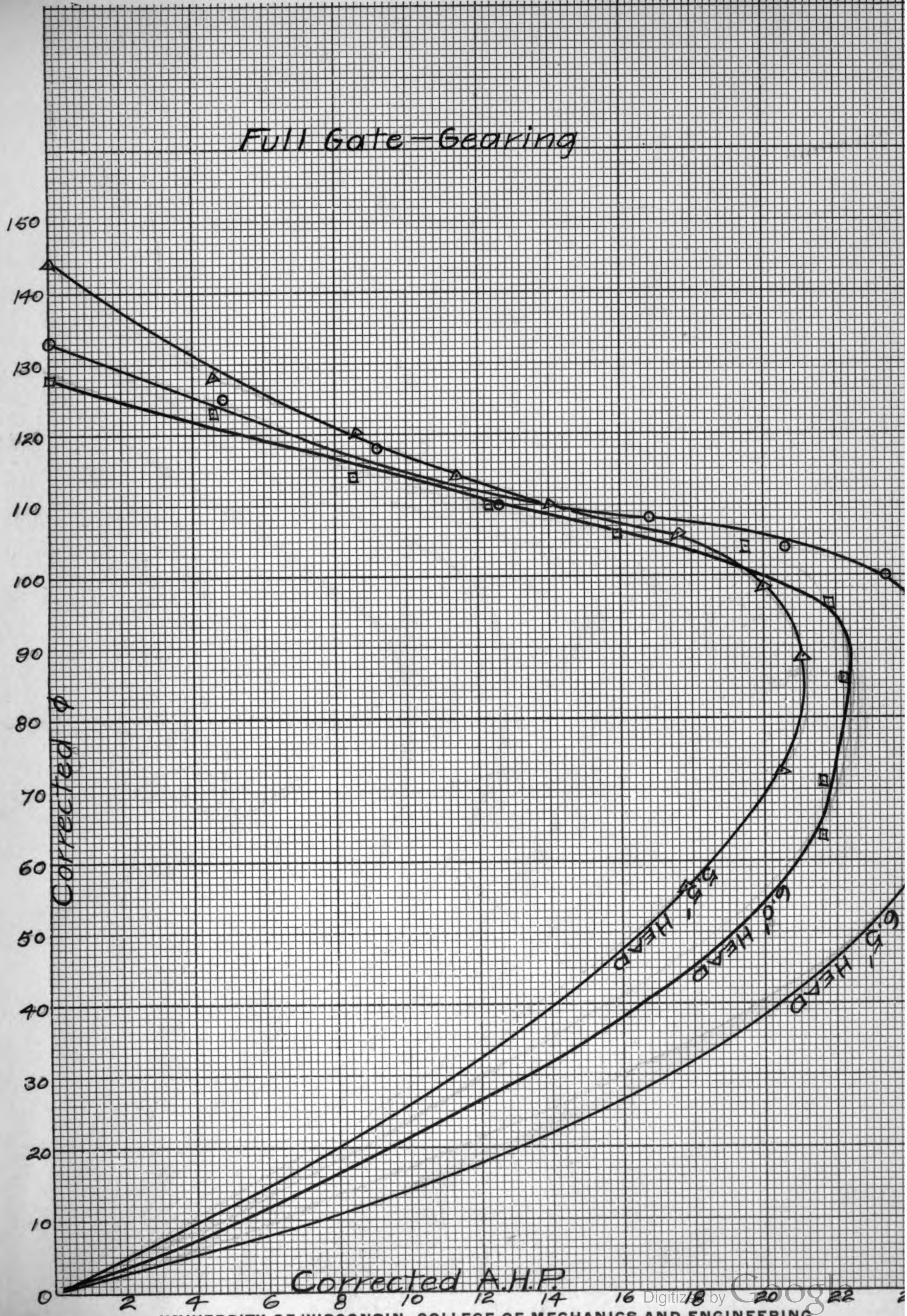
Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ø
						5.0' Head.							
350	.991	7.12	2.10	5.02	00	32.85	0.0	18.7	0.0	.0465	.0279	0.0	.00
275	1.038	7.16	2.15	5.01	46	35.22	8.45	20.0	42.2	.0366	.0205	20.6	.335
250	1.065	7.14	2.17	4.97	78	36.60	13.0	20.6	63.1	.0336	.0180	35.0	.570
220	1.073	7.11	2.19	4.92	98	37.01	14.4	20.6	69.7	.0298	.0158	44.1	.72
190	1.082	7.25	2.19	5.06	116	37.48	14.7	21.6	68.1	.0250	.0132	51.6	.84
160	1.049	7.22	2.16	5.06	124	35.78	13.22	20.6	64.2	.0210	.0117	55.1	.898
100	1.028	7.17	2.14	5.03	147	34.71	9.8	19.9	49.2	.0133	.0075	65.7	1.07
70	1.022	7.21	2.13	5.08	159	34.40	7.45	11.9	37.4	.0092	.0053	70.6	1.15
50	1.016	7.17	2.11	5.06	166	34.10	5.55	19.6	28.2	.0066	.0038	73.9	1.21
25	1.012	7.19	2.12	5.07	177	33.90	2.95	19.5	15.1	.0033	.0019	78.7	1.28
00	.997	7.09	2.10	4.99	188	33.15	0.0	18.8	0.0	.00	.00	84.4	1.37
						4.5' Head.							
287	.960	6.61	2.06	4.55	00	31.32	0.0	16.2	0.0	.0420	.0253	0.0	.00
210	1.026	6.54	2.12	4.42	79	34.6	11.1	17.4	63.9	.0317	.0170	37.6	.613
180	1.039	6.63	2.14	4.49	102	35.27	12.3	18.0	68.2	.0268	.0142	48.2	.786
150	1.025	6.63	2.13	4.50	113	34.56	11.3	17.7	64.0	.0222	.0120	53.3	.872
125	1.007	6.07	2.12	4.55	125	33.65	10.4	17.4	59.9	.0183	.0102	58.6	.956
100	.998	6.64	2.10	4.54	135	33.20	9.00	17.1	51.6	.0147	.0083	63.4	1.04
75	.995	6.69	2.09	4.60	145	33.05	7.27	17.3	42.2	.0108	.0062	67.6	1.10
50	.981	6.62	2.09	4.53	154	32.35	5.10	16.7	30.9	.0074	.0043	72.3	1.18
25	.977	6.58	2.07	4.51	168	32.16	2.80	16.5	17.05	.0037	.0022	79.1	1.29
00	.965	6.54	2.07	4.47	179	31.57	0.0	16.0	0.0	.00	.00	84.7	1.38

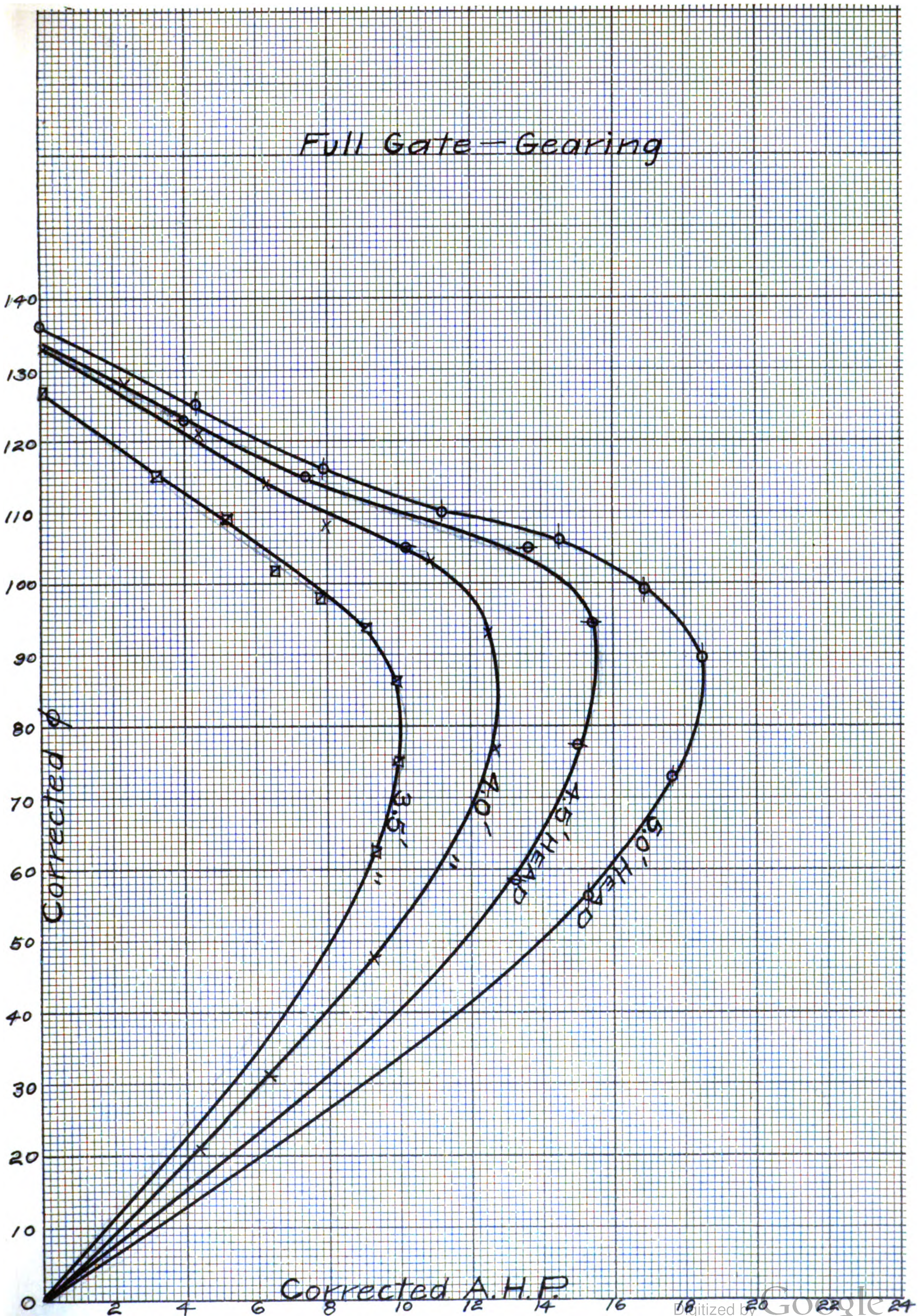
Load	Av. Head Weir	Av. Pit Gage	Tail Gage	Head on Wheel	RPM	Q	Brake H. P.	Theo. H. P.	Eff. %	K	K'	$\frac{N}{H^{1/2}}$	ϕ
4.0' Head.													
300	.920	6.01	2.01	4.00	00	29.39	0.0	13.4	0.0	.0500	.0300	0.0	.00
190	.995	6.13	2.10	4.03	74	33.05	9.4	15.1	61.8	.0314	.0168	36.8	.60
165	1.030	6.13	2.11	4.02	93	34.81	10.2	15.9	64.3	.0274	.0139	46.5	.76
140	.990	6.15	2.10	4.05	104	32.80	9.7	15.1	64.3	.0200	.0124	51.8	.84
120	.983	6.17	2.09	4.08	111	32.45	8.9	15.1	58.7	.0196	.0107	55.0	.90
100	.961	6.11	2.07	4.04	117	31.37	7.8	14.4	54.3	.0164	.0093	58.2	.95
75	.958	6.15	2.06	4.09	130	31.22	6.5	14.5	44.8	.0122	.0070	64.4	1.05
50	.944	6.15	2.03	4.11	142	30.54	4.7	14.3	33.1	.0081	.0047	70.1	1.14
25	.929	6.02	2.01	4.01	152	29.82	2.5	13.6	18.6	.0042	.0025	76.0	1.24
00	.928	6.04	2.02	4.02	167	29.77	0.0	13.6	0.0	.00	.00	83.5	1.36
3.5' Head.													
235	.875	5.49	1.97	3.52	00	27.26	0.0	10.9	0.0	.0445	.0270	0.0	.00
160	.938	5.50	2.03	3.47	63	30.25	6.73	11.9	56.4	.0307	.0167	33.9	.55
140	.949	5.53	2.05	3.48	83	30.79	7.7	12.2	63.5	.0268	.0144	44.6	.73
120	.926	5.58	2.02	3.56	90	29.67	7.2	12.0	59.7	.0225	.0125	47.7	.78
100	.918	5.58	2.02	3.56	101	29.29	6.7	11.9	56.8	.0187	.0106	53.7	.87
75	.911	5.62	2.01	3.61	113	28.96	5.65	11.9	47.6	.0139	.0080	59.5	.97
50	.889	5.44	1.97	3.47	123	27.91	4.1	11.0	37.3	.0096	.0056	66.1	1.08
25	.862	5.38	1.94	3.44	135	26.65	2.3	10.4	21.6	.0048	.0030	73.0	1.19
00	.887	5.49	1.98	3.51	158	27.82	0.0	11.1	0.0	.00	.00	84.3	1.38



UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING


Discharge Curve
Full Gate - Gearing
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
32
36
40
44
48
52
3.5 FT. HEAD
4.0 FT. HEAD
4.5 FT. HEAD
5.0 FT. HEAD
5.5 FT. HEAD
6.0 FT. HEAD
6.5 FT. HEAD
Q Cu. ft. per Sec.


Full Gate—Gearing
Corrected φ
Corrected A.H.P.
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
12
14
16
18
20
22
5.5' HEAD
6.0' HEAD
6.5' HEAD



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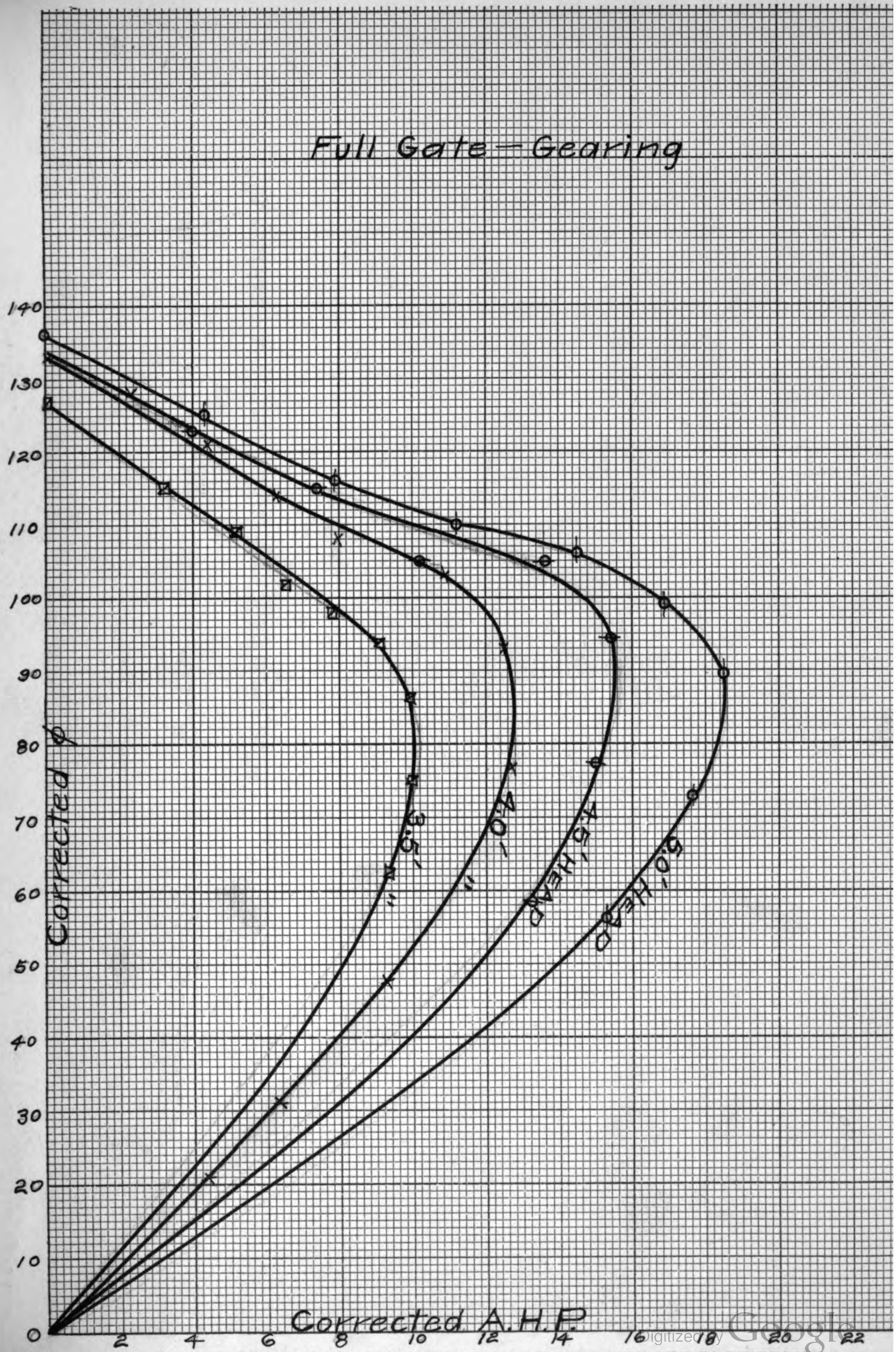

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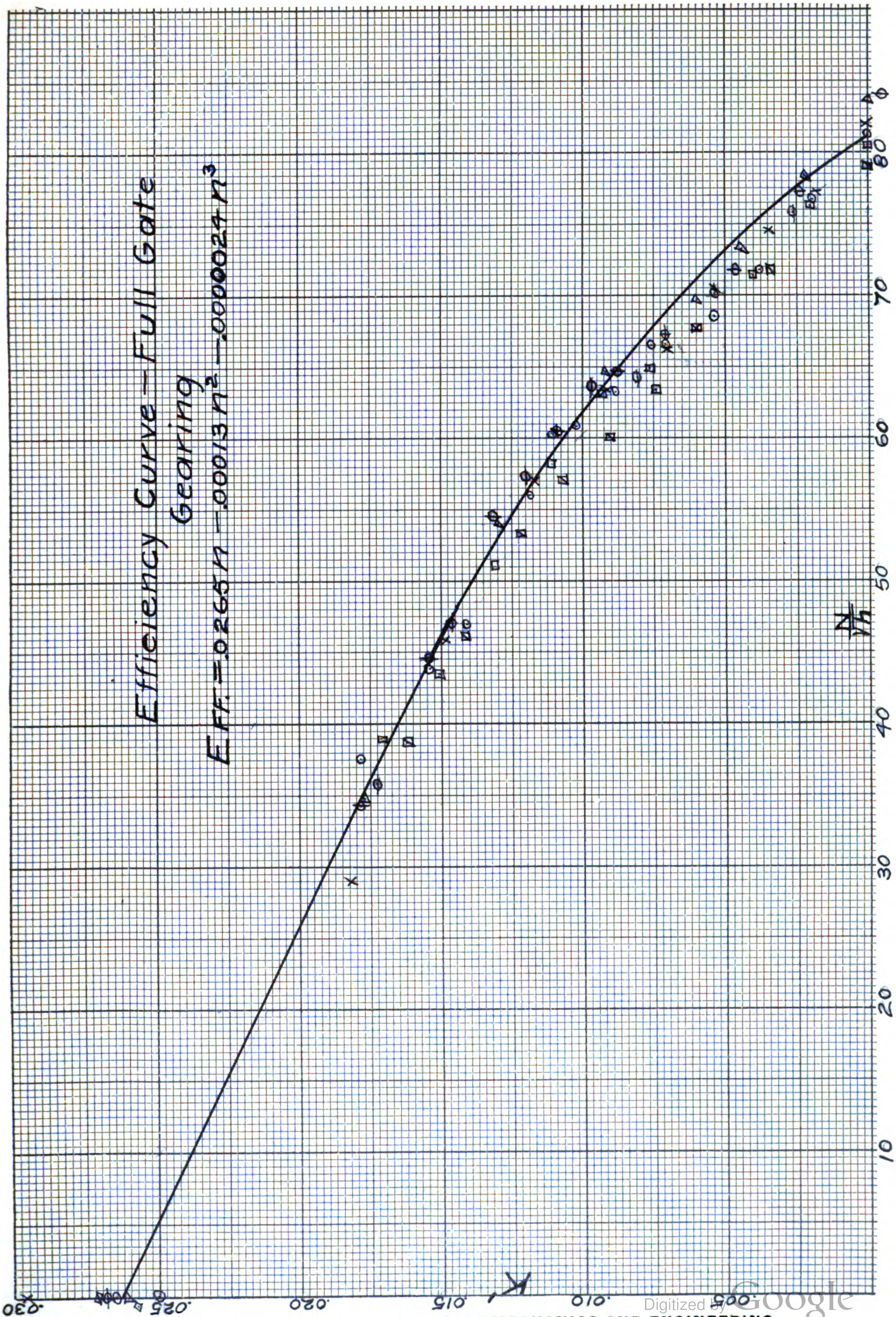
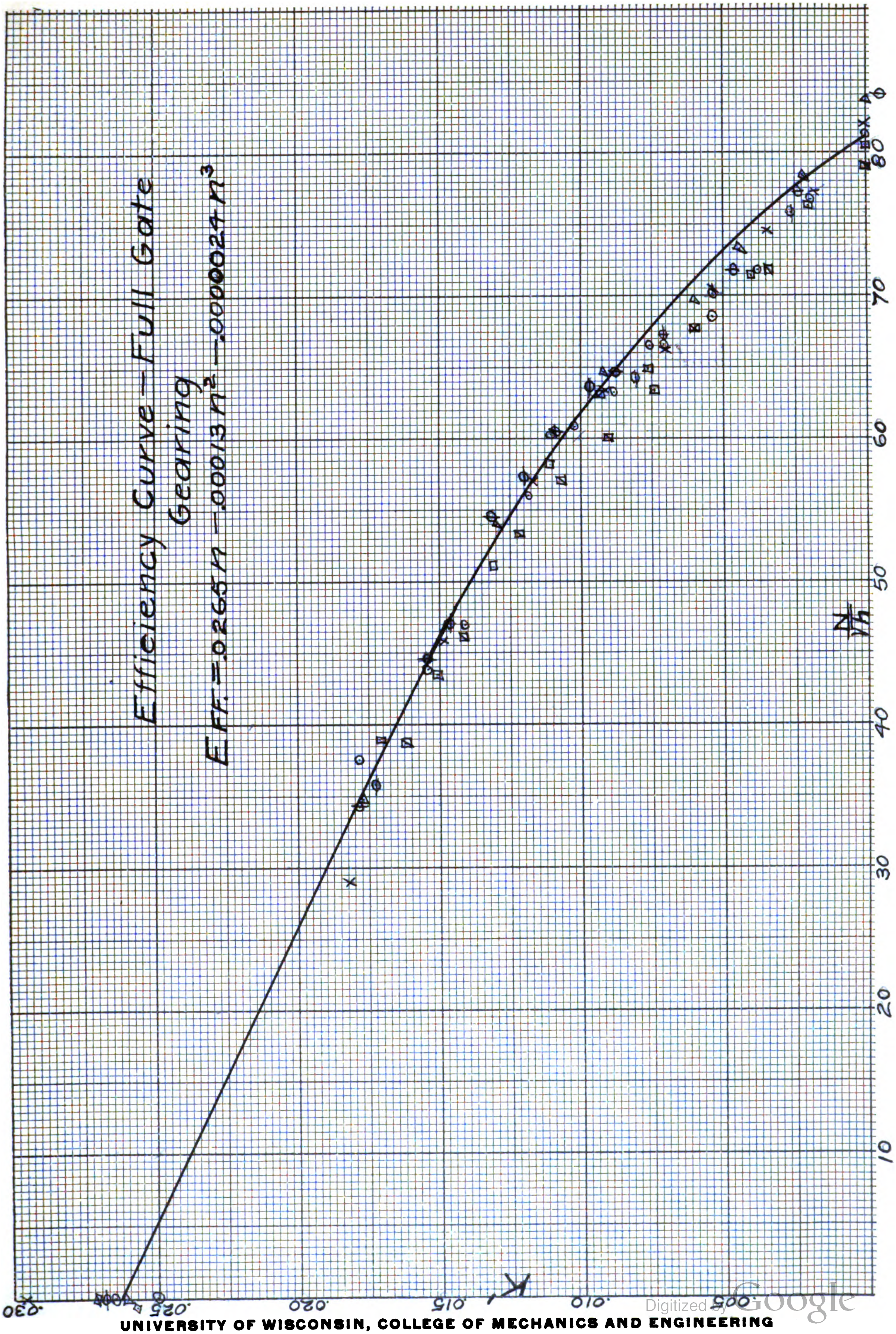
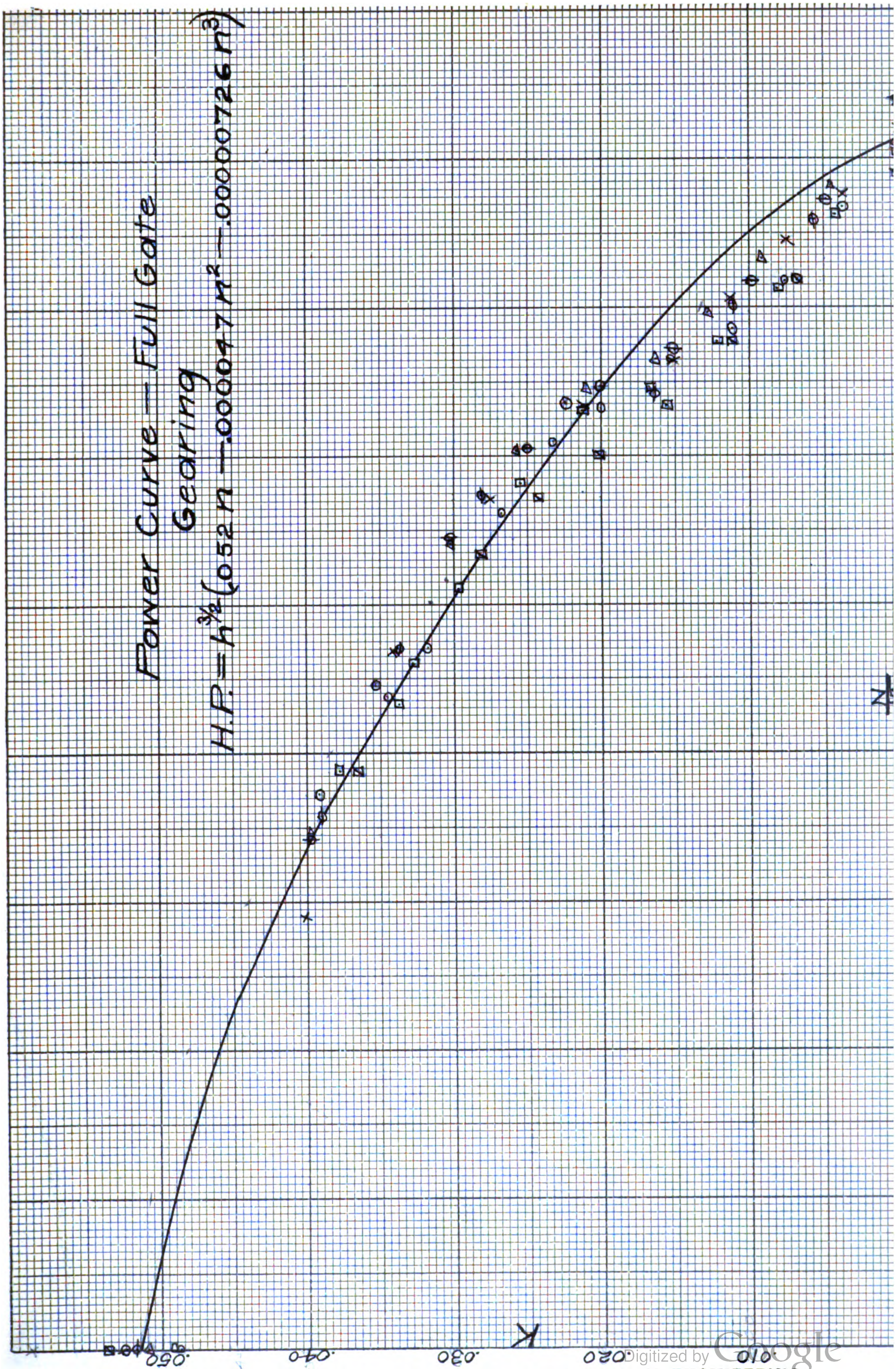


UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING


Efficiency Curve - Full Gate
Gearing
EFF. = .0265 n - .00013 n² - .0000024 n³
K
.030
.025
.020
.015
.010
.005
$\frac{n}{\sqrt{h}}$
10
20
30
40
50
60
70
80

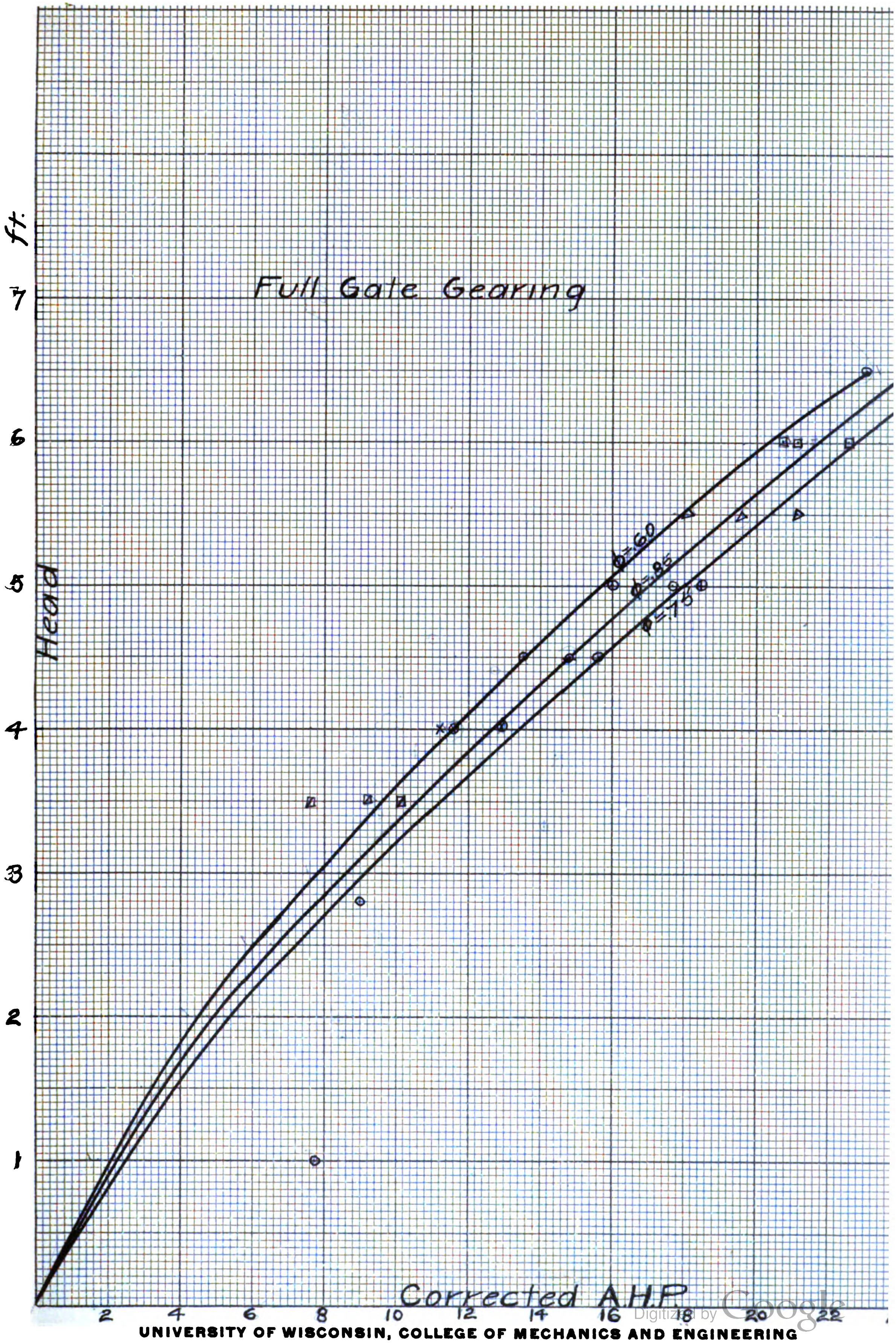


Power Curve — Full Gate

Gearing

$H.P. = h^{3/2}(.052\,n - .00047\,n^2 - .00000726\,n^3)$

UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING



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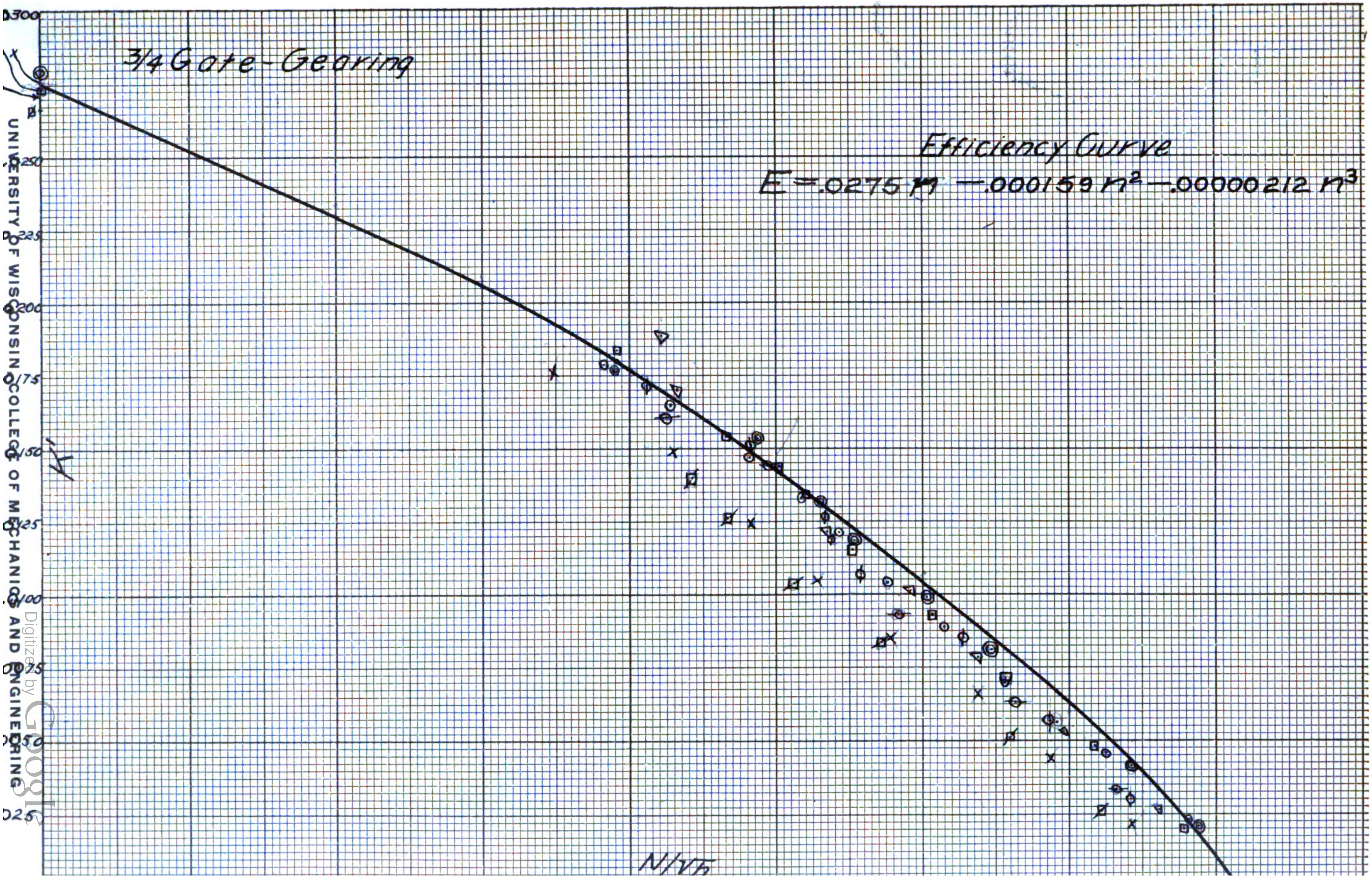
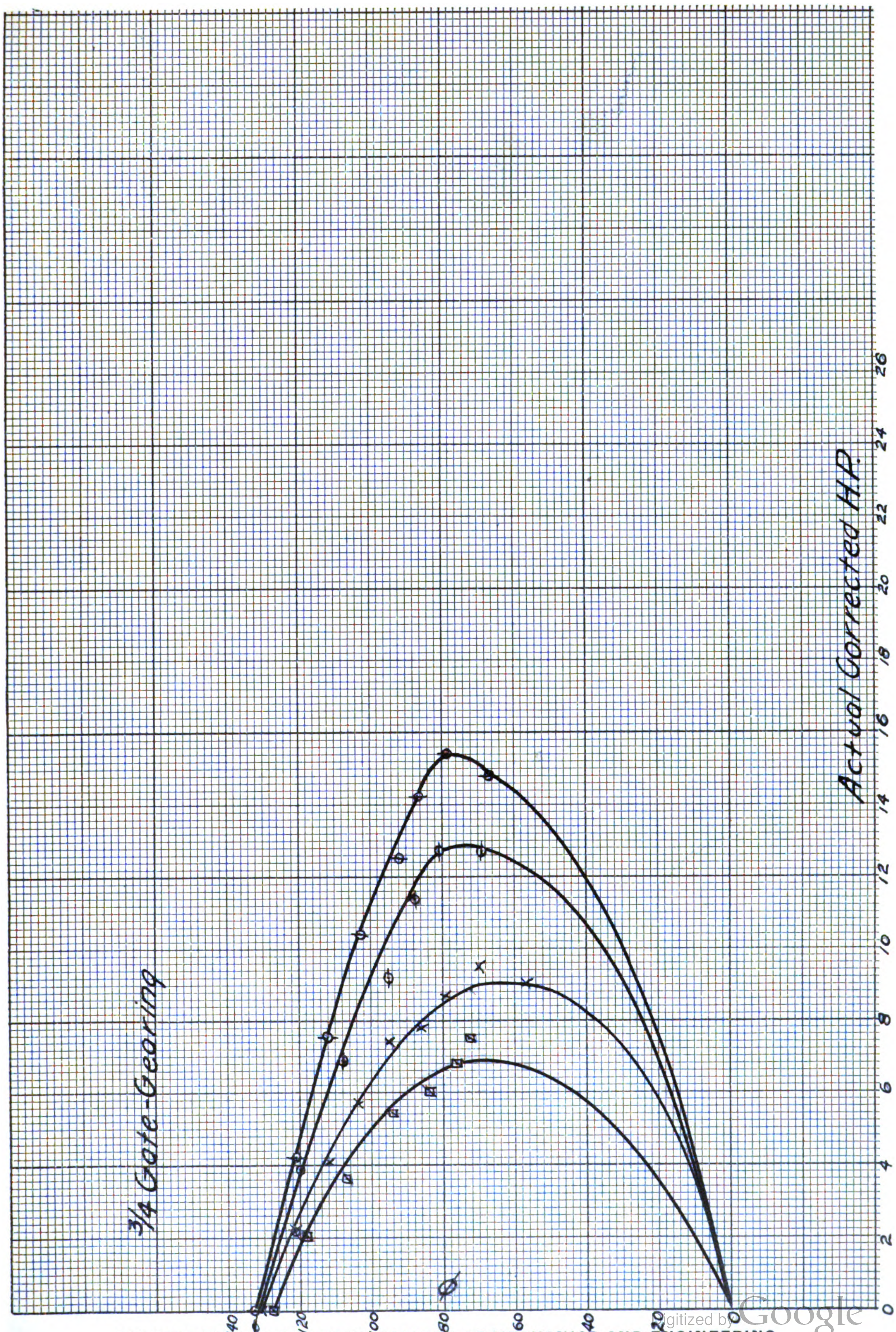
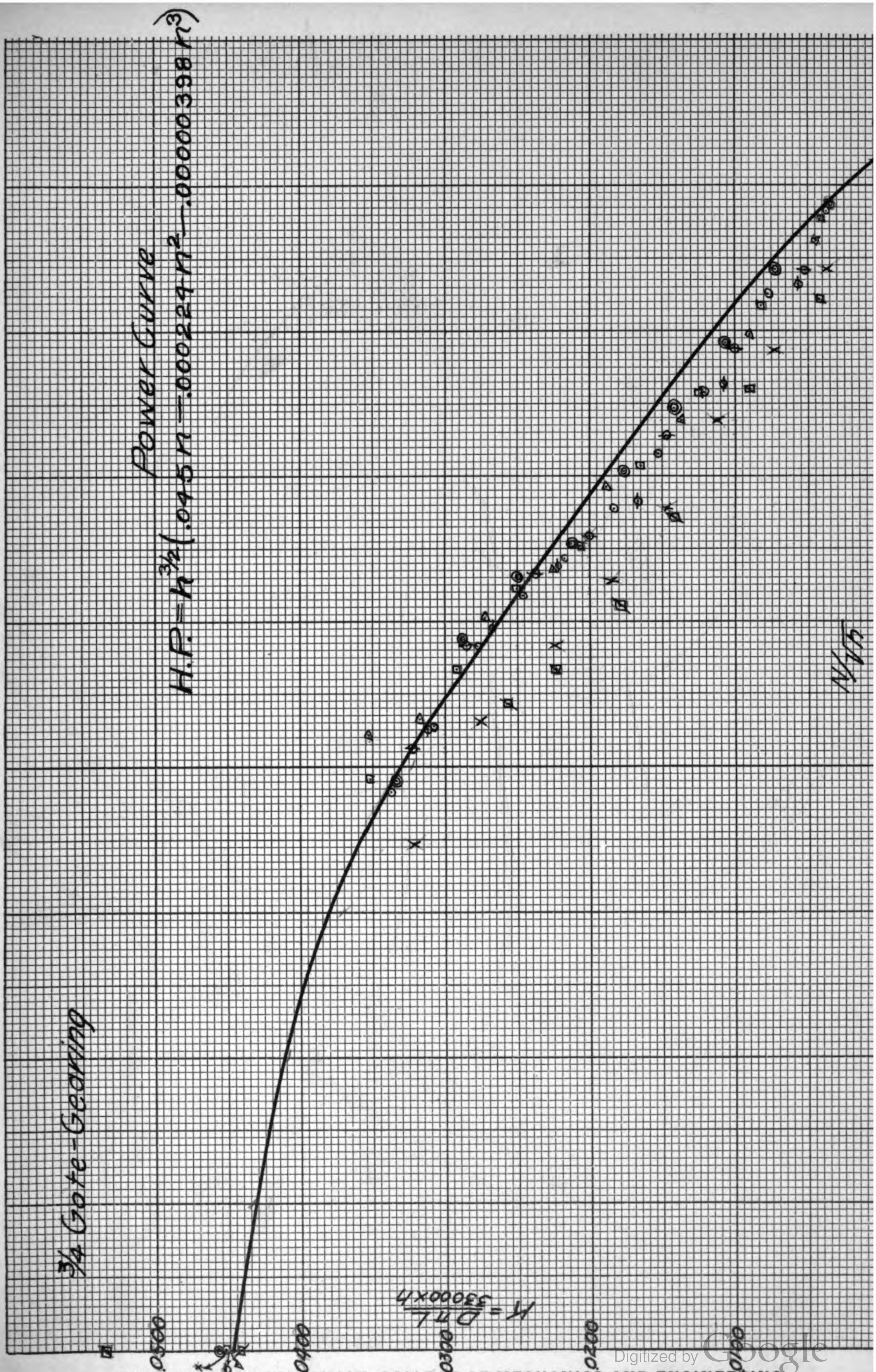

3/4 Gate-Gearing
Efficiency Curve
E = .0275 n − .000159 n² − .00000212 n³
.300
.250
.225
.200
.175
.150
.125
.100
.075
.050
.025
N/√h
UNIVERSITY OF WISCONSIN COLLEGE OF MECHANICS AND ENGINEERING



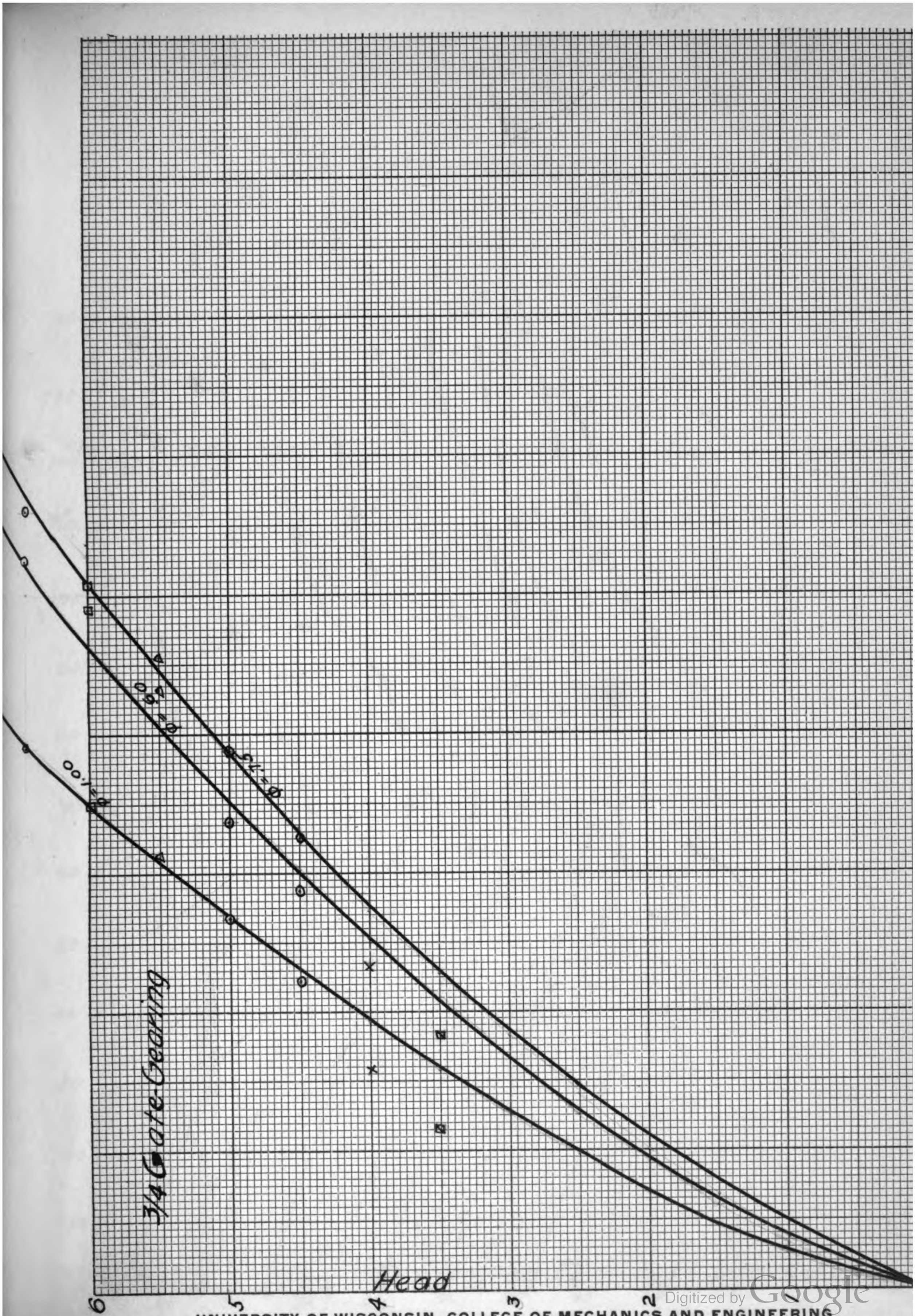
UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING

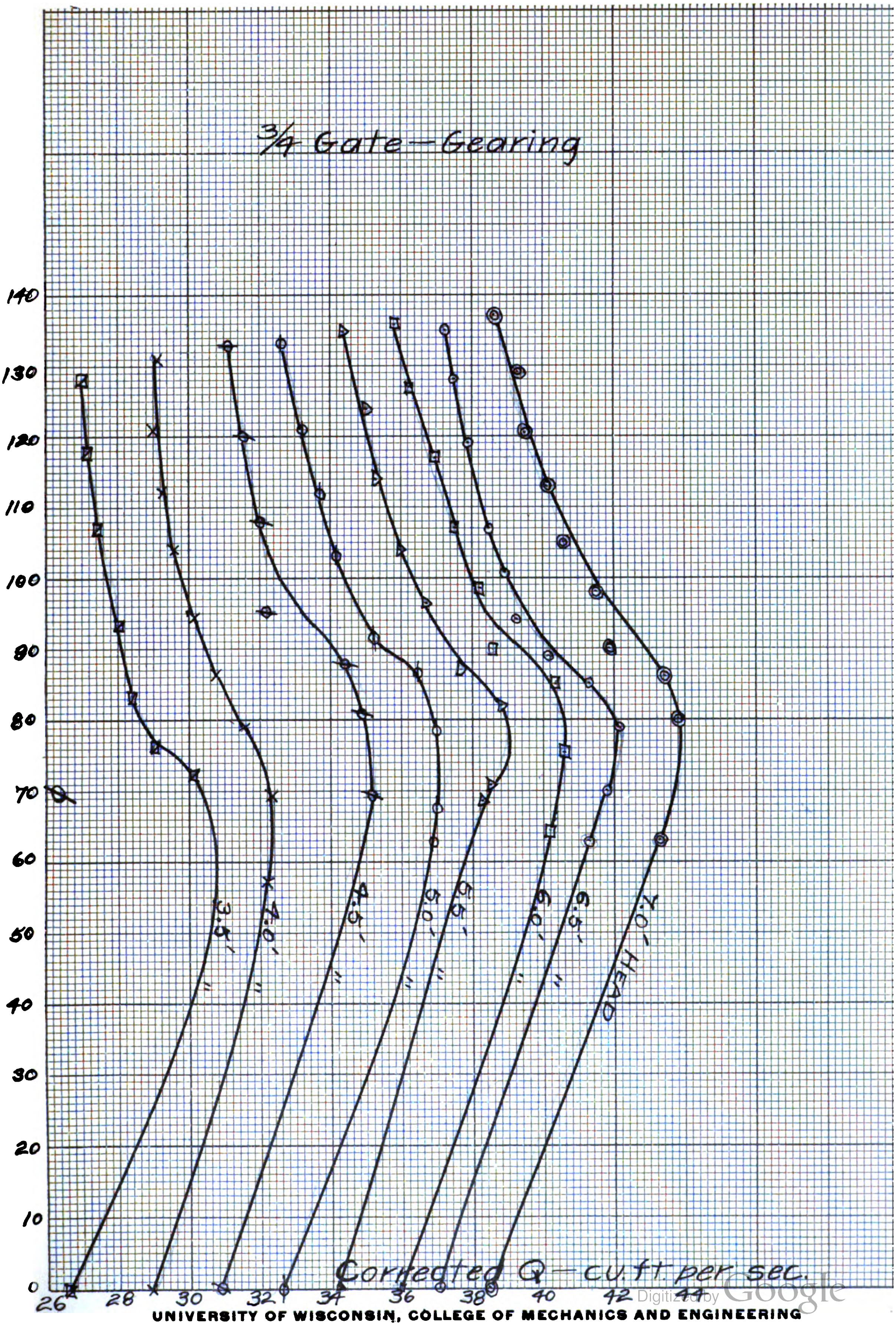


3/4 Gate-Gearing

Power Curve

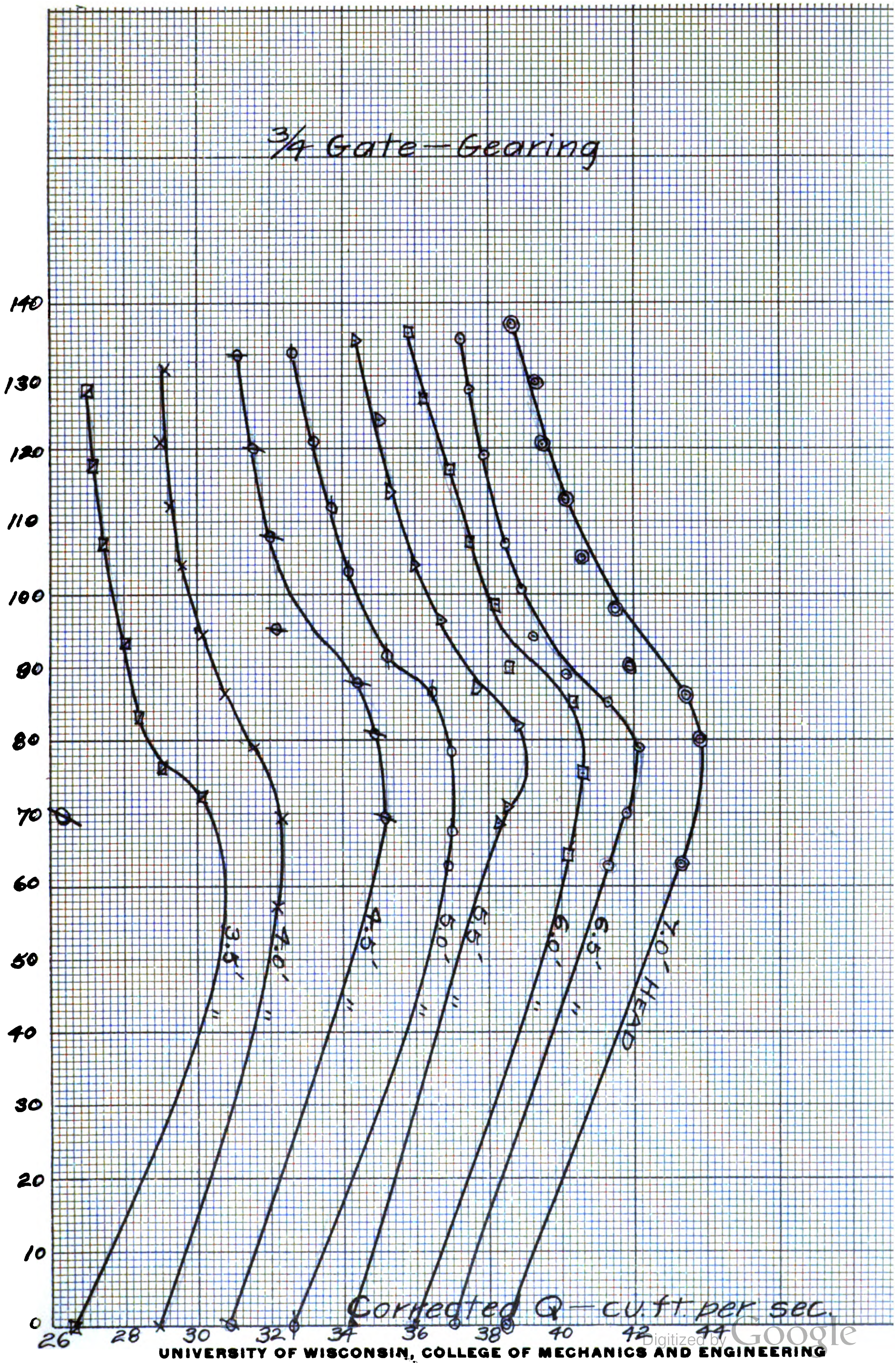
$H.P.=h^{3/2}(.045n-.000224n^2-.00000398n^3)$


3/4 Gate-Gearing
φ=.75
φ=.90
φ=1.00
Head
6
5
4
3
2
1

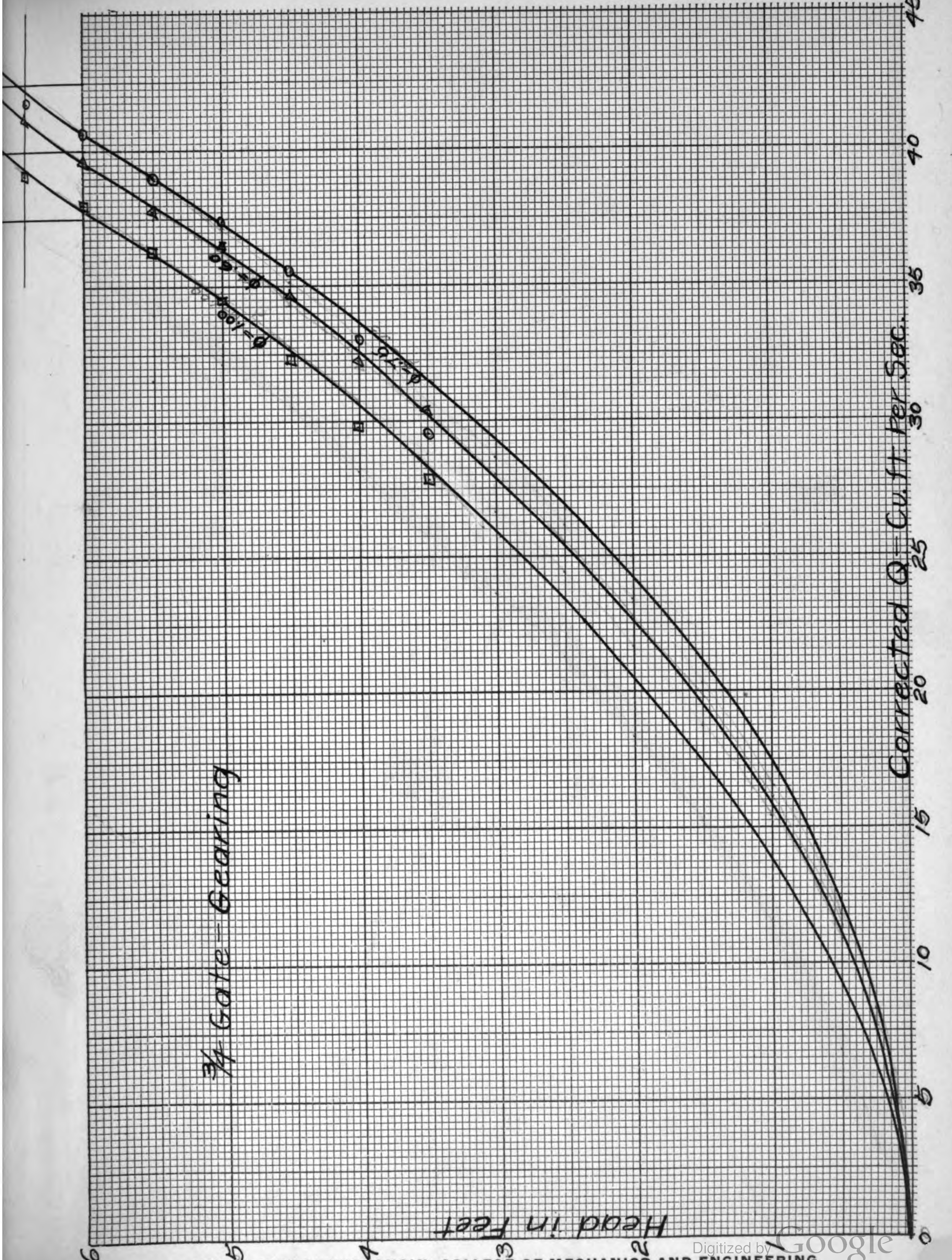


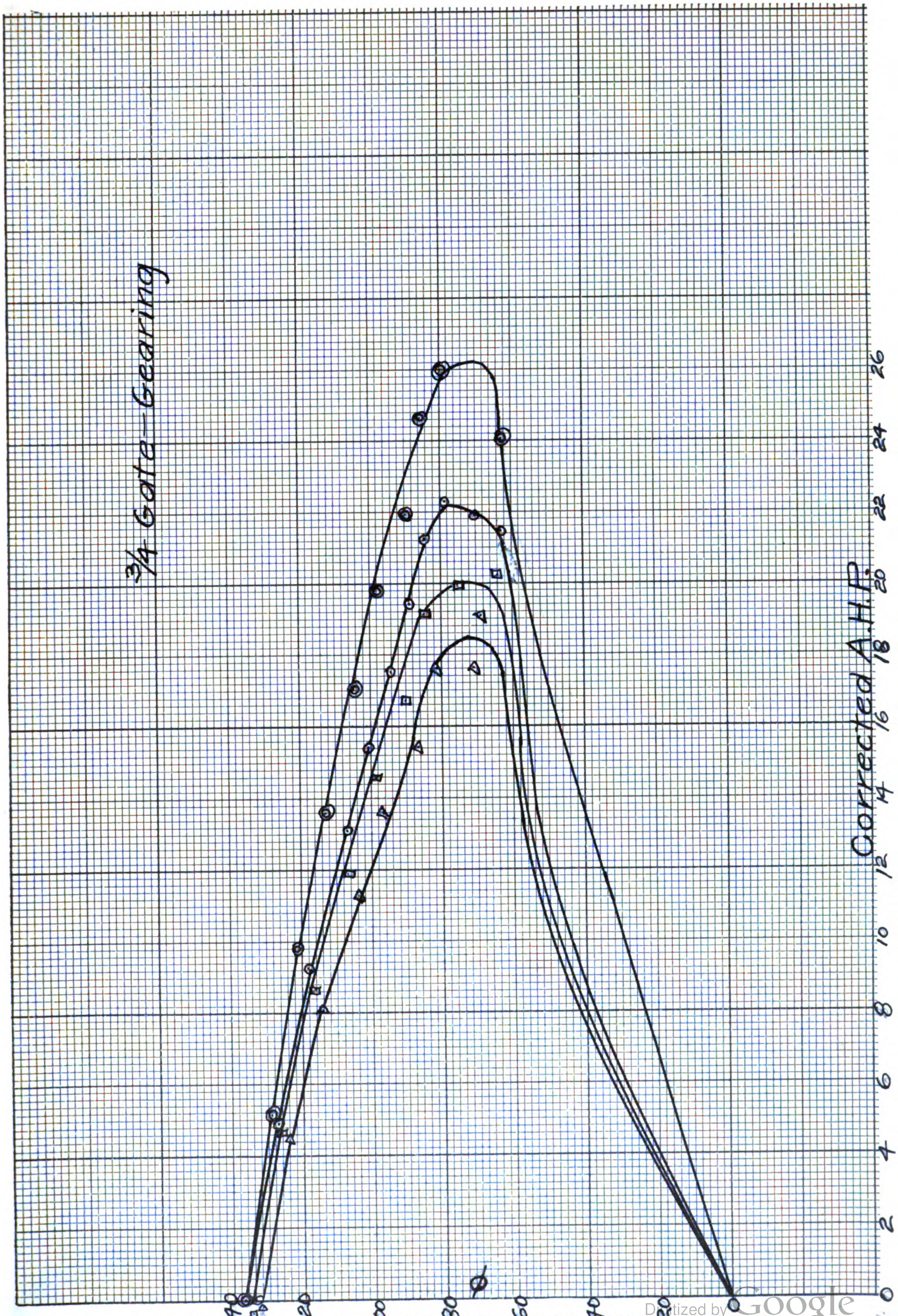
3/4 Gate—Gearing

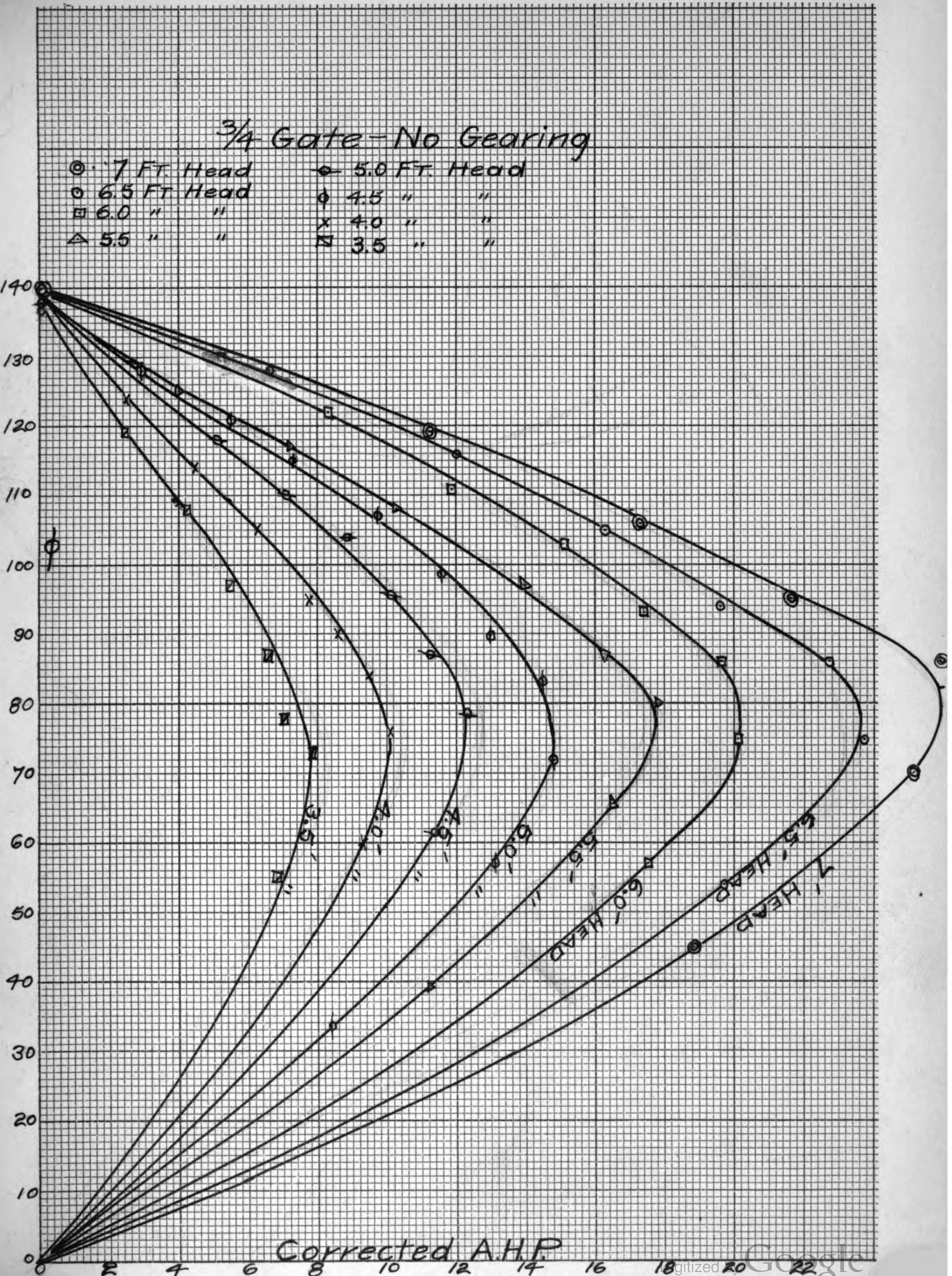
UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING



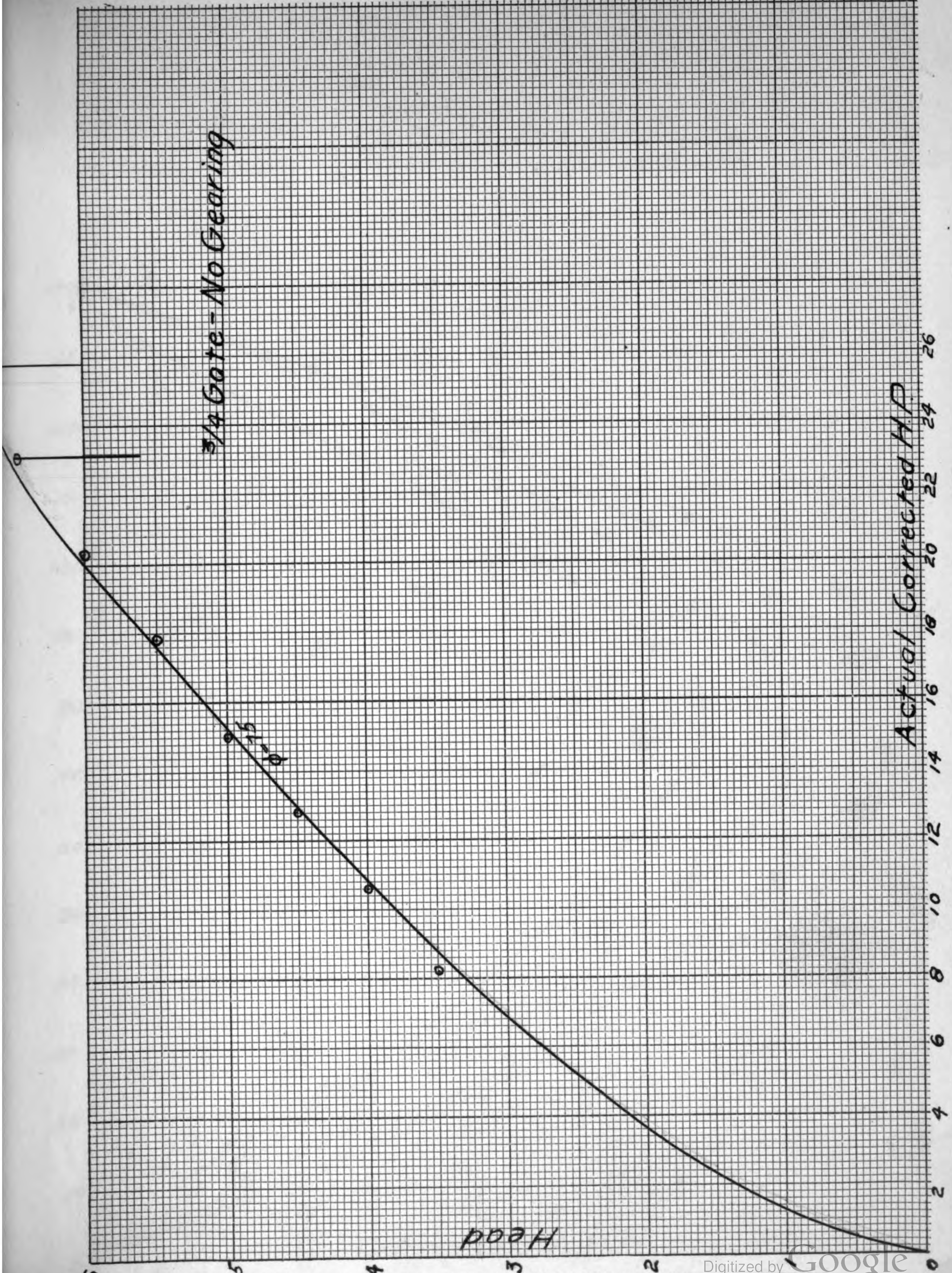
3/4 Gate—Gearing

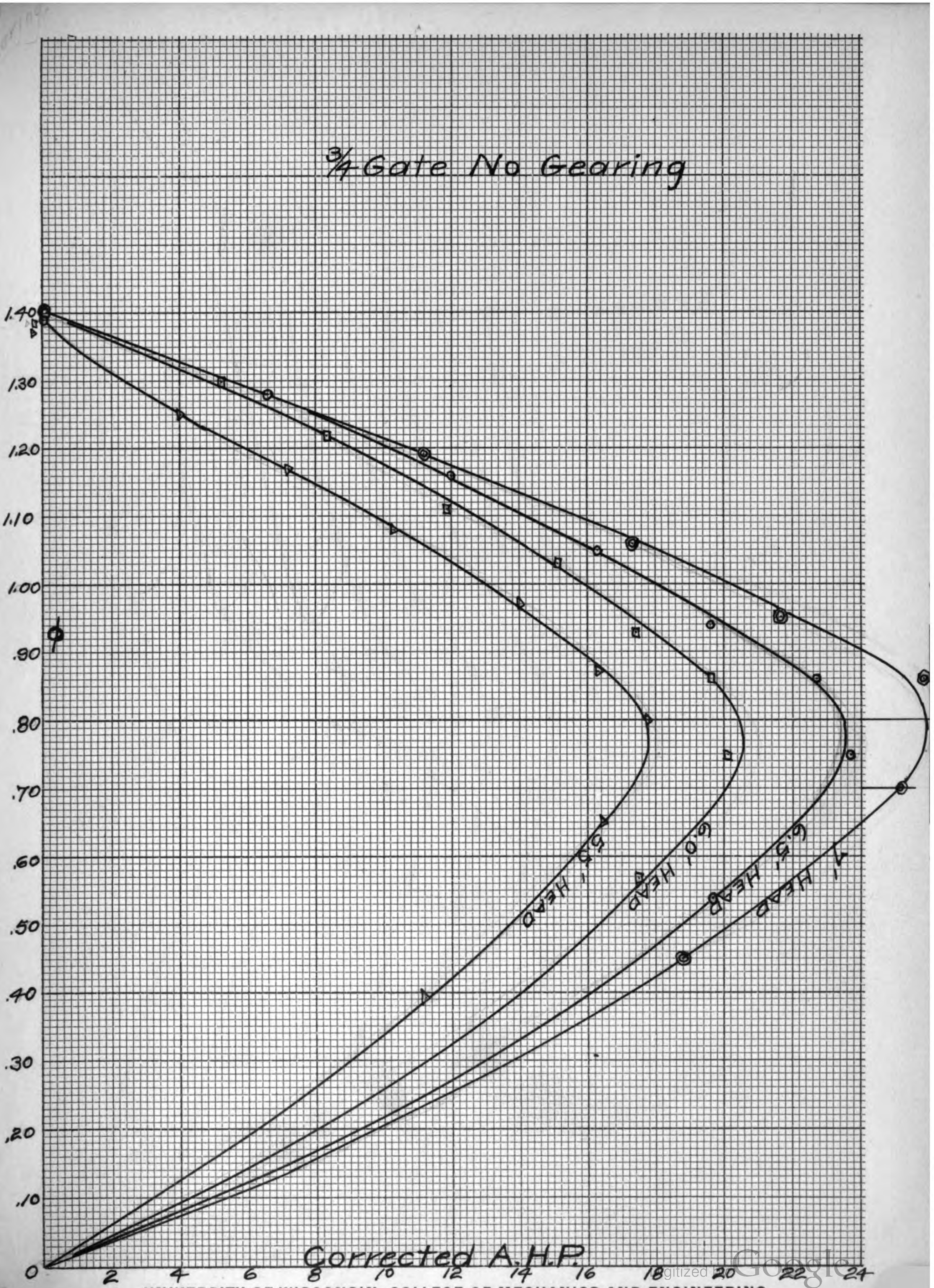

3/4 Gate - Gearing
Head in Feet
Corrected Q = Cu. ft. Per Sec.
φ=1.00
φ=.60
φ=.76
0
1
2
3
4
5
6
0
5
10
15
20
25
30
35
40
45


3/4 Gate-Gearing
Corrected A.H.P.
0
2
4
6
8
10
12
14
16
18
20
22
24
26
140
120
100
80
60
40
20
0

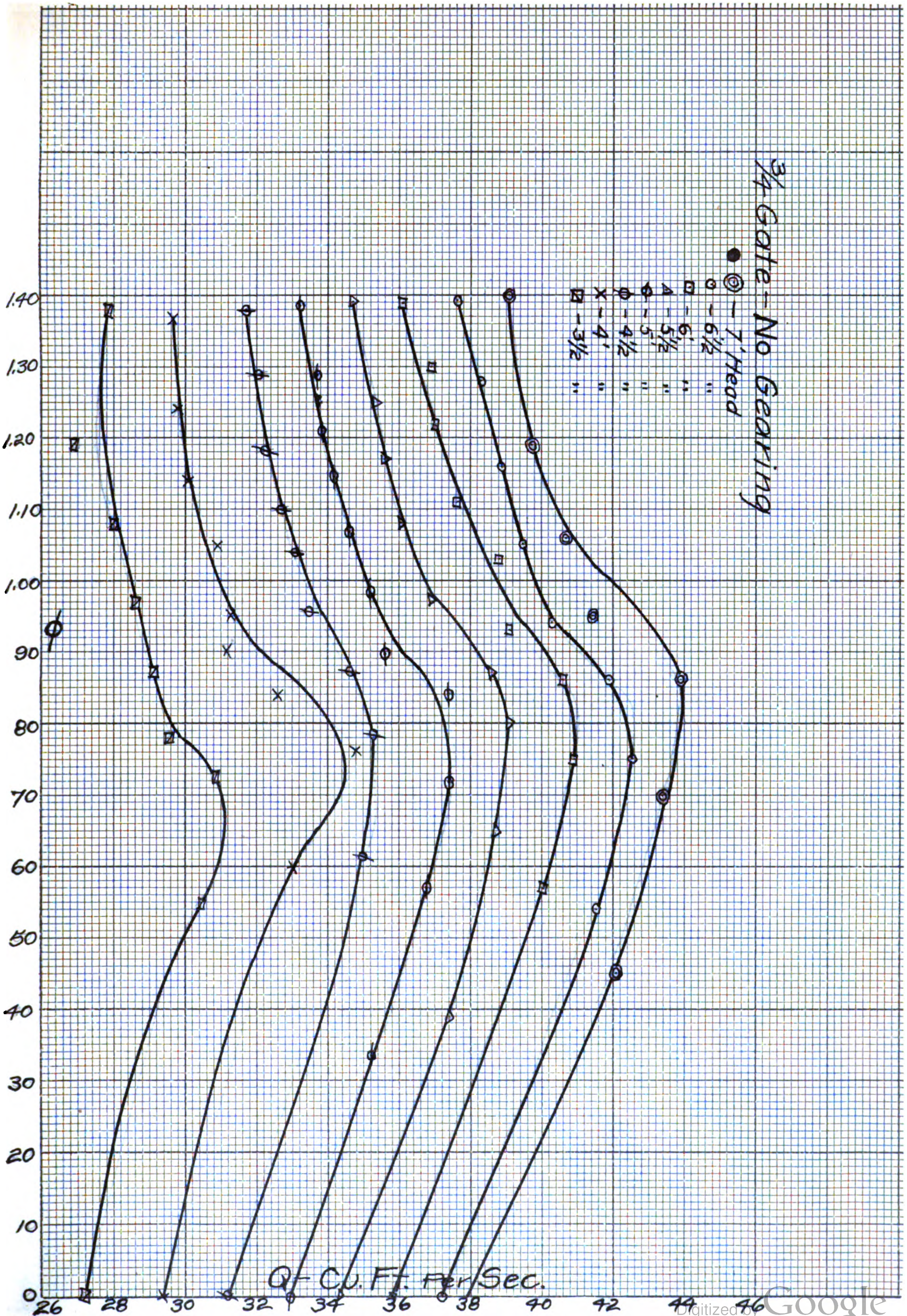


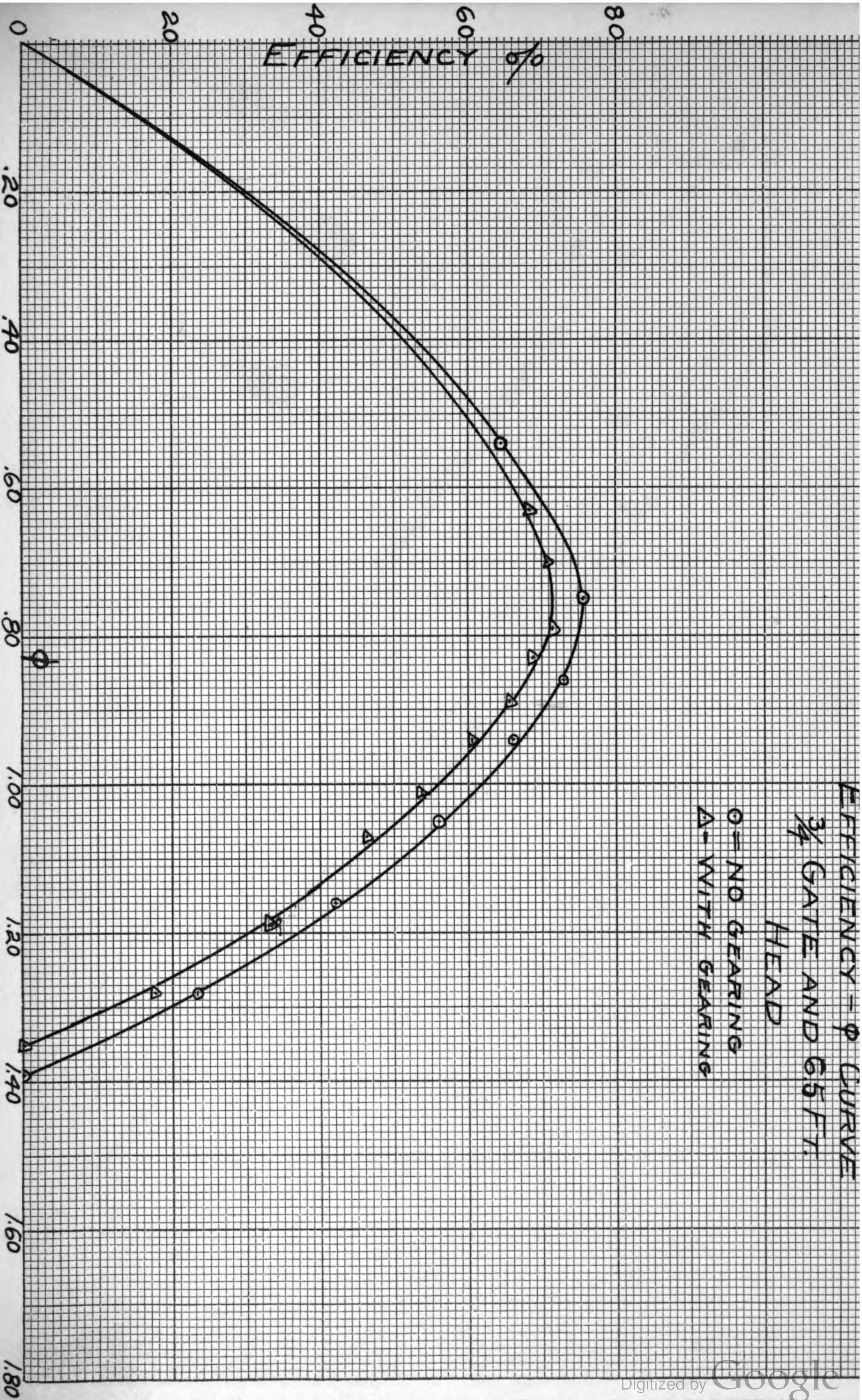
UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING

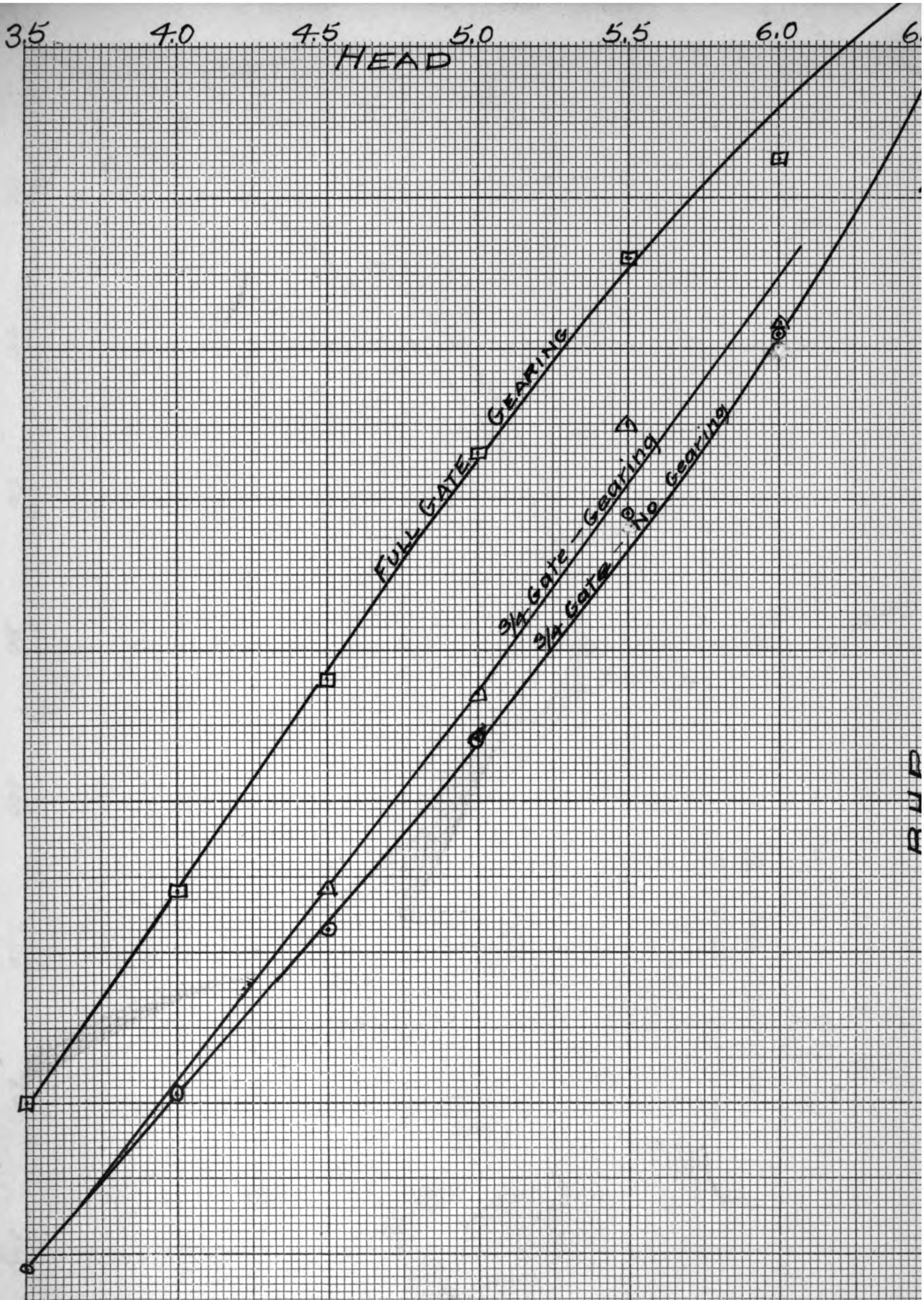

3/4 Gate - No Gearing
Actual Corrected H.P.
Head
φ = .75
0
2
4
6
8
10
12
14
16
18
20
22
24
26
0
1
2
3
4
5
6



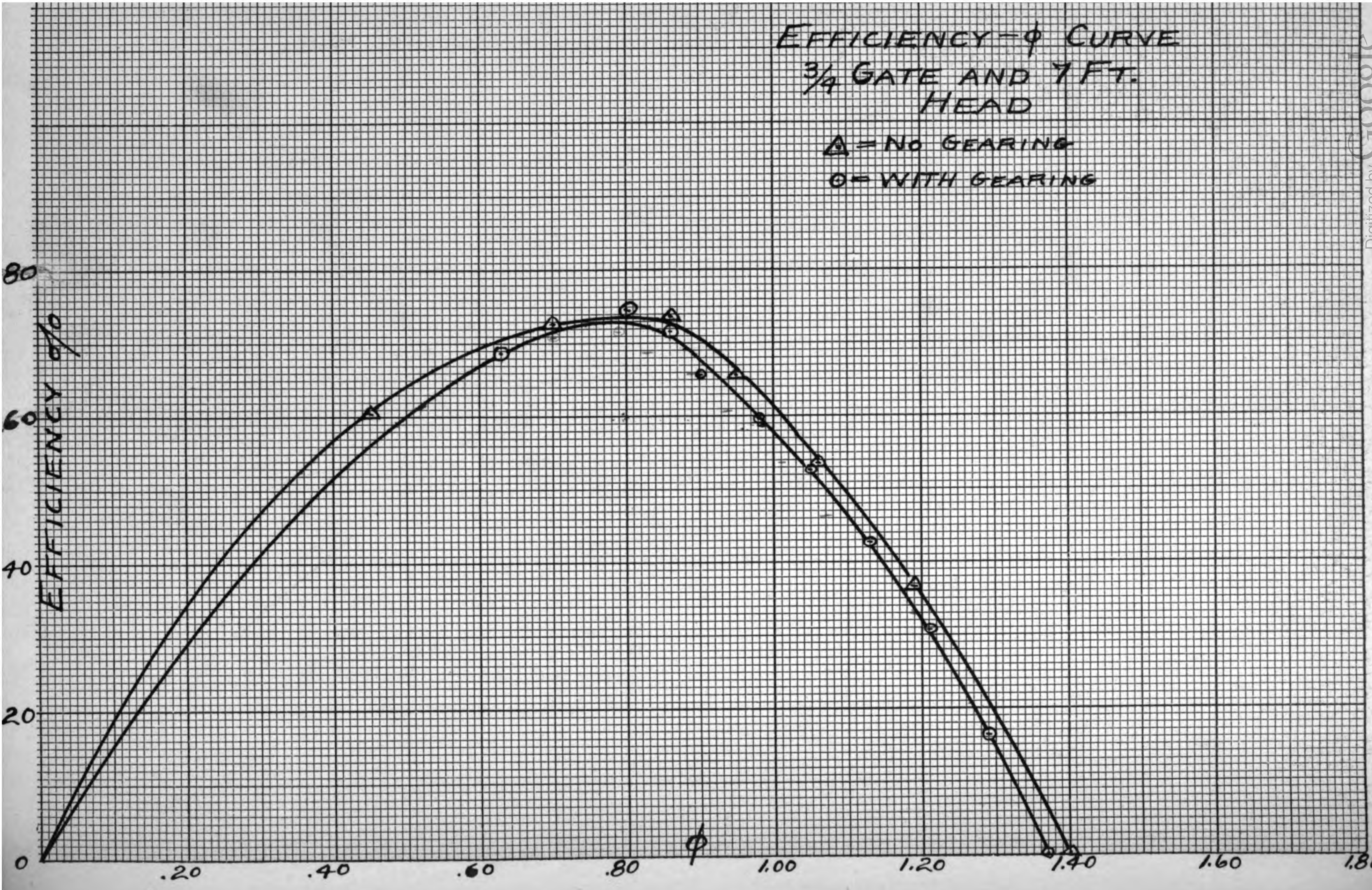
UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING

3/4 Gate - No Gearing
● ◎ - 7' Head
○ - 6½ "
□ - 6' "
△ - 5½ "
φ - 5' "
φ - 4½ "
X - 4' "
☒ - 3½ "
1.40
1.30
1.20
1.10
1.00
90
80
70
60
50
40
30
20
10
0
26
28
30
32
34
36
38
40
42
44
46
Q - Cu. Ft. Per Sec.

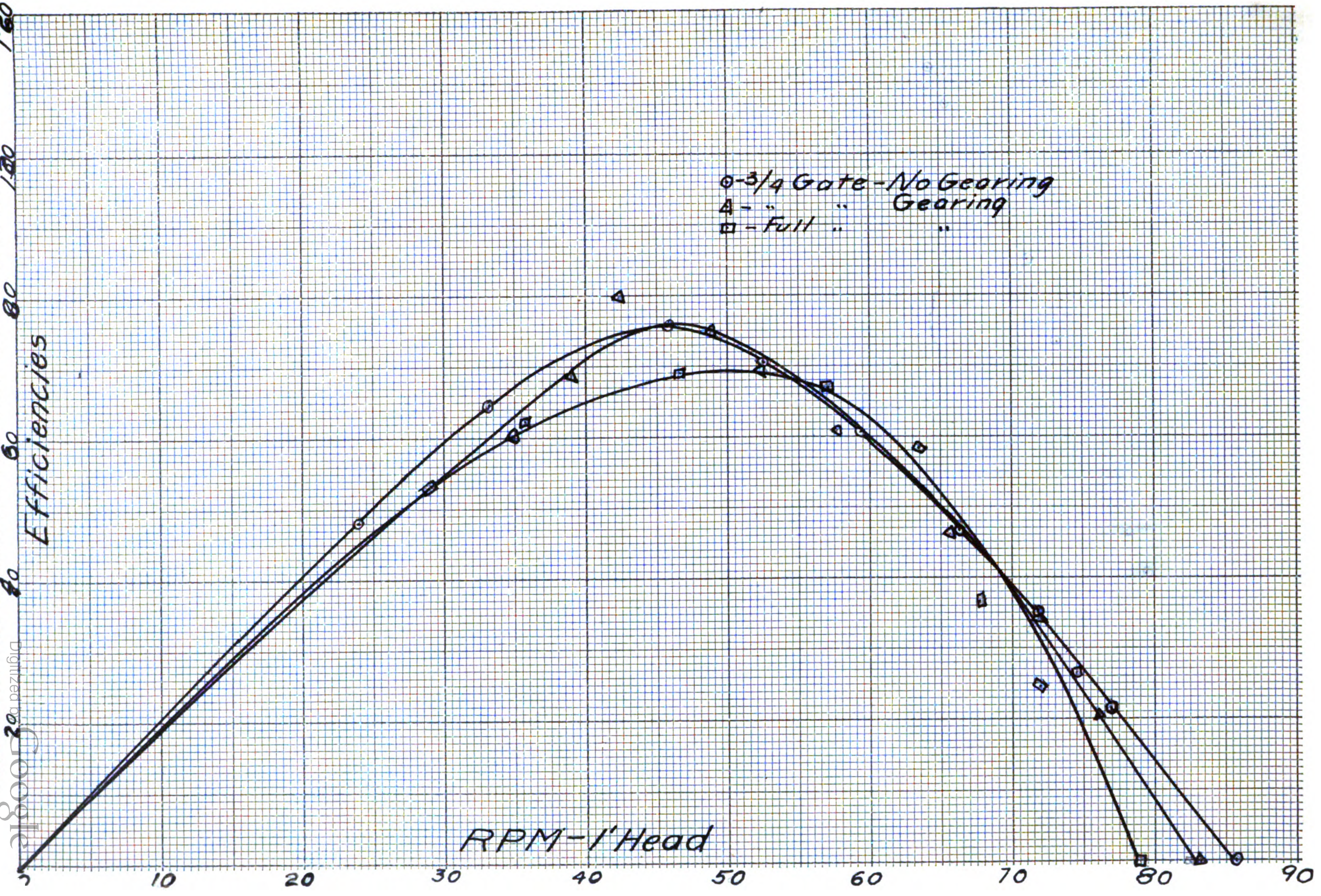

EFFICIENCY - φ CURVE
¾ GATE AND 6.5 FT.
HEAD
⊙ = NO GEARING
Δ - WITH GEARING
EFFICIENCY %
0
20
40
60
80
φ
.20
.40
.60
.80
1.00
1.20
1.40
1.60
1.80



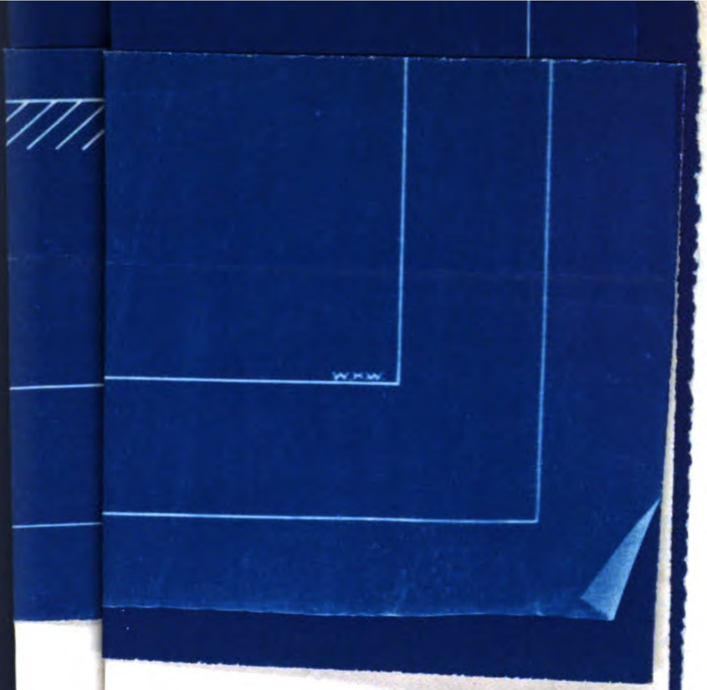
UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING


EFFICIENCY – φ CURVE
3/4 GATE AND 7 FT. HEAD

UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING



UNIVERSITY OF WISCONSIN, COLLEGE OF MECHANICS AND ENGINEERING


W H W

TEST OF AN EIGHTEEN INCH PELTON WATER WHEEL.

INTRODUCTION.

The Pelton Water Wheel is used only with relatively high heads, and it runs with a small quantity of water. With those conditions it is the only wheel which would be suitable to install for service.

At the Hydraulics Laboratory the highest head available for the test of such wheels is 190 feet.

It is very important when installing a wheel of this type to know at what speed you can get the most economy for any given head.

On this same test, and working for a Master's degree, were Wilfred C. Parker, and Charles I. Corp, an assistant professor at Kansas University.

This test was performed during the summer of 1908, and immediately after finishing the test of this Pelton Wheel, the test of the 30 inch Samson Turbine was started.

Apparatus.

The Pelton Wheel tested was very crude, and the cups were quite rough. To have a wheel of this type

with high efficiency the cups should be smooth and well formed.

The water was delivered to the cups through a 7/8 inch nozzle, and the flow regulated by an ordinary valve placed on the pipe about two feet from the nozzle.

On the shaft of the wheel a 12 inch pulley was attached. The small Prony brake, the arm of which was two feet long, was clasped to this wheel. The arm of the brake rested on a small balance and from this balance the load carried by the wheel could be obtained.

The R.P.M. was obtained by a small counter which was held against the end of the shaft.

Each test was three minutes long, and the water used in that time was run into a large tank, and weighed. From this weight the cubic feet per second could be obtained.

The head was measured by a Crosby Gage. This gage was accurately calibrated before the test was commenced.

Results and Computations.

The values under each heading were obtained by using the formulas, reduced for the particular conditions met with.

$$\text{B.H.P.} = \frac{2\pi LWN}{33000} = \frac{4\pi WN}{33000} = .000382\ W\ N \qquad (1)$$

L = length of lever arm in feet = 2

W = load on balance in pounds

N = R.P.M.

$$\text{T.H.P.} = \frac{q\ w\ h}{550} = \frac{q\ h}{8.8} \qquad (2)$$

q = cubic feet per second

w = weight per cubic foot = 62.5

h = head in feet

$$\text{Eff.} = \frac{\text{B.H.P.}}{\text{T.H.P.}} \qquad (3)$$

$$\text{Cubic feet per second} = \frac{W'}{60\ N'} \qquad (4)$$

W' = weight of water in tank

N' = length of experiment in minutes

ϕ represents the ratio between the peripheral velocity of the wheel, and the spouting velocity of the water as it leaves the nozzle.

$$\phi = \frac{\pi DN}{\sqrt{2gh} \times 60 \times 12} = \frac{18 \times N \times \pi}{8.04 \times \sqrt{h} \times 720}$$

$$\phi = .0098 \times \frac{N}{h^{1/2}}$$

D = diameter of wheel in inches = 18

h = head in feet

Several general equations of this type of wheel, or wheels of this type and of the same crudeness in construction were derived. Two of these equations were power equations, and two were efficiency equations. The method of deriving these equations is as follows:

The expression for B.H.P. is $P_a = \frac{2\pi LWN.}{33000.}$ It could be expressed also as $P_a = \frac{q\ h\ e}{8.8}$. We know that $q = ca \times \sqrt{2gh}$ therefore $P_a = \frac{ca \times \sqrt{2gh} \times h \times e}{8.8} = \frac{ca \times \sqrt{2g}\ h^{3/2} e}{8.8}$, and from this we can see that the H.P. varies as $h^{3/2}$ because the rest of the terms are constant.

Now if we divide the expression $\frac{2\pi LWN}{33000}$ by $h^{3/2}$ we get the H.P. under one foot head, or $P_{a_1} = \frac{2\pi LNW}{33000 \times h^{3/2}}$ or $P_{a_1} = \frac{2\pi LW}{33000h} \times \frac{N}{h^{1/2}} = \frac{CW}{h} \times \frac{N.}{h^{1/2}}$ In the data $K = \frac{CW}{h}$.

For each head we plotted values of K as ordinates and values of $\frac{N}{h^{1/2}}$ as abscissae, and found that all points for different heads fell approximately along the same curve except for very low heads where the effect of friction pulled the points down a little below the curve.

To get an equation for this curve we took the general form $X = a + bn + cn^2$, where $n = \frac{N}{h^{1/2}}$ and a, b, and c, are constants to be determined by selecting three points on the curve and solving for them. X of course is the value of $\frac{CW}{h}$ or K.

After getting the values of a, b, and c, the equation for H.P. is obtained by multiplying the second term of the above equation by $h^{3/2} \times n$, and the final equation will be $P_a = h^{3/2}(an + bn^2 + cn^3)$.

The equation is only for the particular sized wheel which was tested.

We know $P_a = CD^2$ if ϕ and h are constant, where D = diameter of wheel in inches. Therefore the equation taking into account the diameter and head is

$$P_a = \frac{Dh^{3/2}}{144}(an + bn^2 + cn^3).$$

To get n for maximum power you differentiate P_a with respect to n and place equal to zero, or $\frac{d(P_a)}{d\,n} = 0$, and solve for n, and this will be the R.P.M. under one foot head which will give the maximum power.

In a similar manner the equation for efficiency is derived.

$$E = \frac{B.H.P.}{T.H.P.} = \frac{2\pi LWN}{33000} \div \frac{q\,w\,h}{550}$$

$$E = \frac{2\pi 8.8\ LWN}{33000\ q\ h}$$

Where L = length of brake arm in feet

W = load on brake in pounds

N = R.P.M.

q = discharge in cubic feet per second

We know that $q = ca\sqrt{2gh}$, therefore $E = \frac{2\pi 8.8\ LWN}{33000ca\sqrt{2gh} \times h} =$

$$\frac{CW}{h} \times \frac{N}{h^{1/2}}$$

$$\frac{CW}{h} = K', \text{ and } \frac{N}{h^{1/2}} = n$$

Values of K' were plotted as ordinates, and values of n plotted as abscissae, and an equation was derived in a similar manner as was the other.

SUMMARY FOR THE PELTON WATER WHEEL.

RPM	Brake Load	Brake H. P.	Theo. H. P.	Eff. %	Cu.Ft. per Sec.	ø	K	$\frac{N}{H^{1/2}}$	K'
40' Head.									
243	7.0	.647	.998	64.8	.219	.376	.0000665	38.4	.0169
270	6.5	.669	.998	67.1	.219	.420	.0000618	42.8	.0157
294	6.0	.672	.999	67.3	.220	.455	.0000571	46.5	.0145
314	5.5	.657	.998	65.8	.219	.485	.0000523	49.7	.0132
337	5.0	.642	.998	64.4	.219	.422	.0000476	53.3	.0121
363	4.5	.622	.998	62.3	.219	.562	.0000428	57.4	.0109
398	4.0	.606	.999	60.6	.220	.615	.0000381	62.9	.0096
412	3.5	.548	.998	54.9	.219	.637	.0000333	65.2	.0084
434	3.0	.496	.998	49.7	.219	.672	.0000285	68.7	.0072
449	2.5	.427	.998	42.8	.219	.696	.0000238	71.0	.0060
463	2.0	.352	.998	35.3	.219	.717	.0000190	73.3	.0048
539	0.0	.00	.998	0.0	.219	.835	.00	85.4	.00
50' Head.									
211	10.0	.804	1.385	58.1	.244	.293	.0000761	29.8	.0195
261	9.0	.894	1.380	64.8	.244	.361	.0000685	36.9	.0175
308	8.0	.929	1.385	67.1	.244	.422	.0000609	43.2	.0155
354	7.0	.943	1.385	68.2	.244	.490	.0000533	50.0	.0138
391	6.0	.895	1.385	64.0	.244	.542	.0000457	55.3	.0117
434	5.0	.826	1.390	59.7	.244	.602	.0000380	61.4	.0097
467	4.0	.712	1.385	51.2	.244	.647	.0000304	66.0	.0078
501	3.0	.571	1.385	41.2	.244	.693	.0000228	70.8	.0058
532	2.0	.404	1.380	29.3	.244	.735	.0000152	75.2	.0039
610	0.0	.00	1.385	0.0	.244	.845	.00	86.3	.00

* * *

RPM	Brake Load	Brake H. P.	Theo. H. P.	Eff. %	Cu.Ft. per Sec.	ϕ	K	$\frac{N}{H^{1/2}}$	K'
				60' Head.					
317	10.0	1.21	1.79	67.4	.268	.400	.0000634	40.8	.0165
352	9.0	1.21	1.79	67.4	.262	.444	.0000571	45.4	.0134
390	8.0	1.19	1.79	66.5	.262	.492	.0000508	50.3	.0132
425	7.0	1.13	1.79	63.1	.262	.536	.0000444	54.8	.0115
463	6.0	1.06	1.79	59.2	.262	.585	.0000381	59.8	.0099
495	5.0	.94	1.79	52.5	.262	.625	.0000317	63.8	.0082
527	4.0	.80	1.79	44.9	.262	.665	.0000254	68.0	.0066
566	3.0	.64	1.79	36.0	.262	.716	.0000191	73.0	.0049
606	2.0	.46	1.79	25.8	.262	.766	.0000127	78.1	.0033
660	0.0	.00	1.79	0.0	.262	.833	.00	85.2	.00
				70' Head.					
247	14.0	1.32	2.26	58.5	.2835	.288	.0000762	29.6	.0198
333	12.0	1.52	2.26	67.2	.2835	.390	.0000654	39.8	.0169
404	10.0	1.54	2.26	68.1	.2835	.473	.0000544	48.3	.0141
475	8.0	1.45	2.26	64.1	.2835	.555	.0000435	56.8	.0113
538	6.0	1.23	2.26	54.4	.2835	.630	.0000326	64.4	.0085
600	4.0	.92	2.26	40.5	.2835	.701	.0000218	71.7	.0057
673	2.0	.51	2.26	22.6	.2835	.786	.0000109	80.5	.0028
723	0.0	.00	2.26	0.0	.2835	.846	.00	86.6	.00
				80' Head.					
268	16.0	1.63	2.75	59.2	.303	.293	.0000760	29.9	.0198
344	14.0	1.83	2.75	66.5	.303	.375	.0000665	38.4	.0173
423	12.0	1.92	2.76	49.5	.304	.462	.0000570	47.2	.0147
482	10.0	1.83	2.74	66.7	.302	.525	.0000475	53.7	.0124
550	8.0	1.67	2.75	60.7	.303	.601	.0000380	61.5	.0099
616	6.0	1.41	2.74	51.5	.302	.675	.0000284	68.8	.0075
678	4.0	1.03	2.74	37.6	.302	.741	.0000190	75.7	.0050
740	2.0	.56	2.74	20.5	.302	.809	.0000095	82.6	.0025
775	0.0	.00	2.74	0.0	.302	.849	.00	86.5	.00

* * *

RPM	Brake Load	Brake H. P.	Theo. H. P.	Eff. %	Cu.Ft. per Sec.	ϕ	K	$\frac{N}{H^{1/2}}$	K'
90' Head.									
344	16.0	2.10	3.28	64.0	.321	.354	.0000677	36.2	.0177
422	14.0	2.25	3.28	68.6	.321	.436	.0000593	44.5	.0154
473	12.0	2.16	3.28	65.9	.320	.489	.0000548	49.9	.0132
537	10.0	2.05	3.27	62.7	.320	.554	.0000423	56.6	.0111
605	8.0	1.84	3.27	56.3	.320	.607	.0000339	63.9	.0088
670	6.0	1.53	3.26	46.9	.319	.691	.0000254	70.7	.0066
733	4.0	1.12	3.26	34.4	.319	.756	.0000169	77.4	.0045
784	2.0	.60	3.27	18.4	.320	.810	.0000085	82.8	.0032
817	0.0	.00	3.27	0.0	.320	.845	.00	86.2	.00
100' Head.									
272	20.5	2.12	3.85	55.1	.338	.267	.0000781	27.2	.0202
377	18.0	2.58	3.85	67.0	.339	.369	.0000685	37.7	.0178
463	15.5	2.74	3.84	71.4	.338	.454	.0000590	46.3	.0154
528	13.0	2.62	3.84	68.2	.338	.518	.0000495	52.8	.0129
591	10.5	2.36	3.84	61.5	.338	.580	.0000400	59.1	.0104
678	8.0	2.08	3.84	53.6	.338	.665	.0000305	67.8	.0079
754	5.5	1.58	3.84	41.1	.338	.738	.0000210	75.4	.0055
816	3.0	.93	3.84	24.2	.338	.800	.0000114	81.6	.0030
869	0.0	.00	3.84	0.0	.338	.852	.00	86.4	.00
110' Head.									
239	24.0	2.19	4.42	49.6	.354	.224	.0000832	22.8	.0217
331	21.0	2.65	4.43	59.9	.354	.310	.0000728	31.6	.0189
447	18.0	3.06	4.41	69.4	.353	.418	.0000624	42.6	.0163
530	15.0	3.03	4.40	68.9	.353	.495	.0000520	50.6	.0136
613	12.0	2.80	4.40	63.6	.353	.574	.0000416	58.6	.0109
714	9.0	2.45	4.40	55.7	.353	.668	.0000312	68.1	.0082
798	6.0	1.82	4.41	41.3	.353	.747	.0000208	76.1	.0054
866	3.0	.99	4.41	22.4	.354	.812	.0000104	82.6	.0027
915	0.0	.00	4.41	0.0	.354	.857	.00	87.4	.00

120' Head.

RPM	Brake Load	Brake H. P.	Theo. H. P.	Eff. %	Cu.Ft. per Sec.	ϕ	K	$\frac{N}{H^{1/2}}$	K'
233	26.0	2.31	5.00	46.2	.366	.234	.0000825	21.3	.0217
344	23.0	3.01	5.02	60.0	.367	.342	.0000730	31.4	.0191
459	20.0	3.50	5.02	69.9	.368	.412	.0000635	41.9	.0167
532	17.0	3.44	5.01	68.6	.367	.476	.0000539	48.5	.0142
608	14.0	3.24	5.01	64.7	.367	.543	.0000444	55.1	.0117
708	11.0	2.96	5.02	59.0	.368	.634	.0000349	64.6	.0091
798	8.0	2.43	5.02	48.5	.368	.714	.0000254	72.8	.0067
866	5.0	1.65	5.02	32.9	.367	.776	.0000159	79.1	.0042
953	0.0	0.0	5.01	0.0	.367	.851	.00	87.0	.00

130' Head.

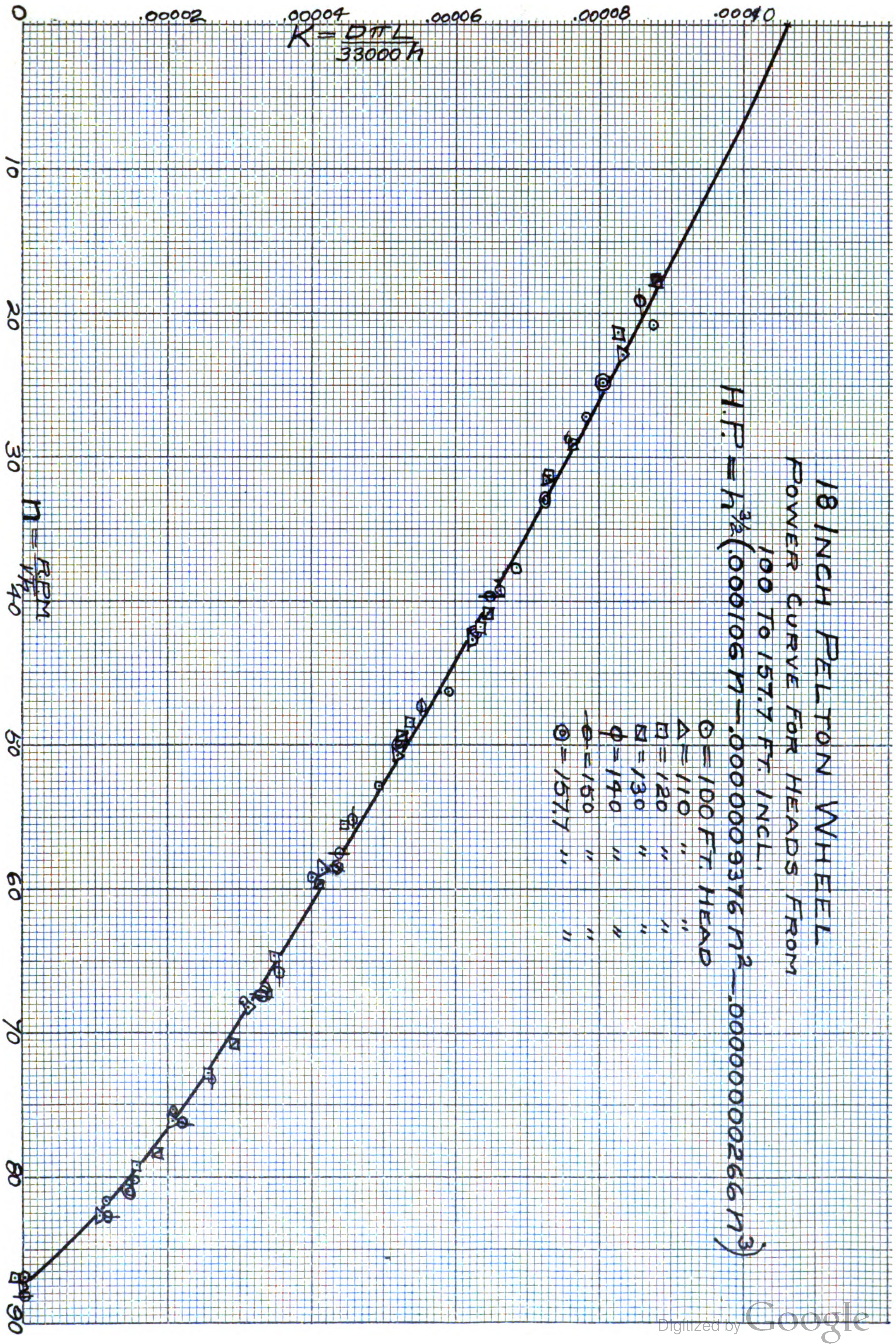
RPM	Brake Load	Brake H. P.	Theo. H. P.	Eff. %	Cu.Ft. per Sec.	ϕ	K	$\frac{N}{H^{1/2}}$	K'
202	30.0	2.31	5.69	40.6	.384	.174	.0000880	17.7	.0229
333	26.0	3.29	5.70	57.7	.385	.286	.0000763	29.2	.0198
466	22.0	3.90	5.68	68.6	.384	.401	.0000645	40.9	.0168
563	18.0	3.86	5.67	68.1	.384	.485	.0000527	49.4	.0138
681	14.0	3.63	5.66	64.0	.384	.585	.0000410	59.6	.0107
805	10.0	3.06	5.67	54.0	.384	.694	.0000293	70.6	.0077
893	6.0	2.04	5.66	36.1	.383	.769	.0000184	78.3	.0046
994	0.0	0.0	5.70	0.0	.386	.855	.00	87.1	.00

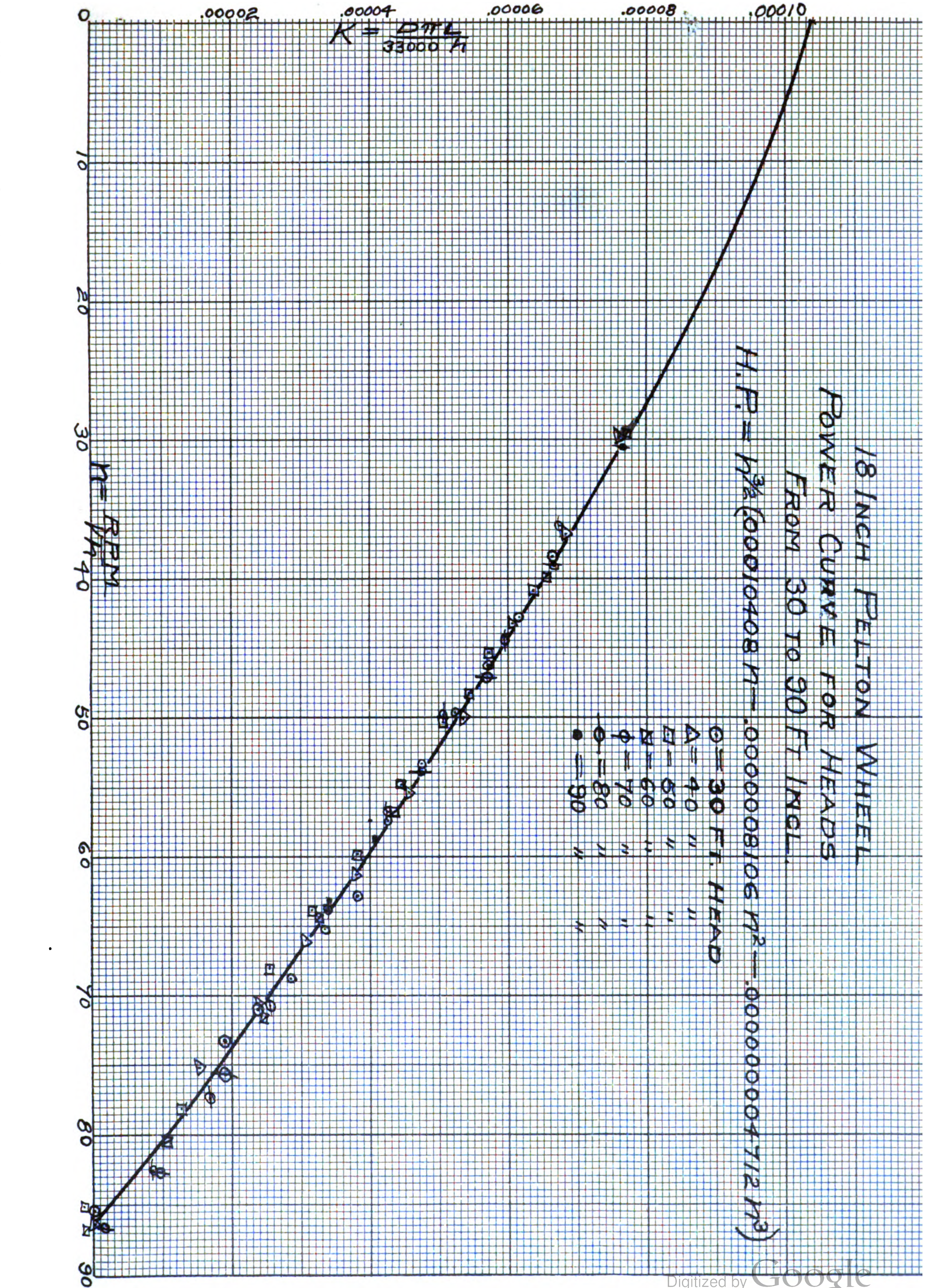
140' Head.

RPM	Brake Load	Brake H. P.	Theo. H. P.	Eff. %	Cu.Ft. per Sec.	ϕ	K	$\frac{N}{H^{1/2}}$	K'
343	28.0	3.65	6.35	57.5	.400	.284	.0000760	28.9	.0198
470	24.0	4.30	6.35	67.7	.399	.390	.0000650	39.7	.0170
574	20.0	4.37	6.36	68.6	.400	.474	.0000530	48.6	.0141
684	16.0	4.17	6.34	65.8	.398	.567	.0000440	57.5	.0114
804	12.0	3.68	6.34	58.2	.398	.665	.0000330	67.5	.0086
901	8.0	2.74	6.34	43.2	.398	.746	.0000220	76.2	.0057
982	4.0	1.49	6.34	23.5	.399	.814	.0000110	82.7	.0028
1046	0.0	0.0	6.36	0.0	.400	.866	.00	88.2	.00

RPM	Brake Load	Brake H. P.	Theo. H. P.	Eff. %	Cu.Ft. per Sec.	ϕ	K	$\frac{N}{H^{1/2}}$	K'
					150' Head.				
234	33.75	3.01	6.97	43.2	.410	.187	.0000856	19.1	.0226
354	30.0	4.05	7.05	57.5	.413	.282	.0000762	28.9	.0199
481	26.0	4.77	7.05	67.6	.413	.384	.0000662	39.3	.0172
580	22.0	4.87	7.04	69.2	.412	.464	.0000552	47.4	.0146
675	18.0	4.64	7.02	66.1	.412	.538	.0000457	55.2	.0120
793	14.0	4.23	7.02	60.2	.412	.634	.0000355	65.8	.0093
987	10.0	3.42	7.02	48.7	.412	.716	.0000254	73.3	.0067
982	6.0	2.25	7.01	32.1	.411	.785	.0000153	80.3	.0040
1067	0.0	0.0	7.00	0.0	.411	.852	.00	87.2	.00
					157.7' Head.				
312	33.52	3.98	7.55	52.7	.422	.244	.0000805	24.9	.0212
414	30.0	4.73	7.60	62.2	.423	.323	.0000724	33.0	.0188
528	26.0	5.23	7.38	69.1	.423	.414	.0000627	42.2	.0164
625	22.0	5.23	7.58	69.1	.423	.490	.0000523	49.8	.0139
733	18.0	5.02	7.56	66.7	.422	.574	.0000435	58.5	.0114
844	14.0	4.49	7.58	59.3	.423	.660	.0000338	67.4	.0082
944	10.0	3.59	7.58	47.4	.423	.738	.0000242	75.3	.0063
1015	6.0	2.30	7.58	30.5	.423	.792	.0000145	81.0	.0038
1100	0.0	0.0	7.58	0.0	.423	.858	.00	87.8	.00

* * *


18 INCH PELTON WHEEL
POWER CURVE FOR HEADS FROM
100 TO 157.7 FT. INCL.
$H.P. = h^{3/2}(.000106\,n - .0000009376\,n^2 - .00000000266\,n^3)$
⊙ = 100 FT. HEAD
△ = 110 "
⊡ = 120 "
⊠ = 130 "
ϕ = 140 "
-o- = 150 "
⊚ = 157.7 "
$K = \frac{D\pi L}{33000\,h}$
$n = \frac{RPM}{h^{1/2}}$
0
.00002
.00004
.00006
.00008
.00010
10
20
30
40
50
60
70
80
90



18 Inch Pelton Wheel
Power Curve for Heads
From 30 to 90 Ft. Incl.

$H.P. = n^{3/2}(.00010408n - .000008106n^2 - .000000004712n^3)$

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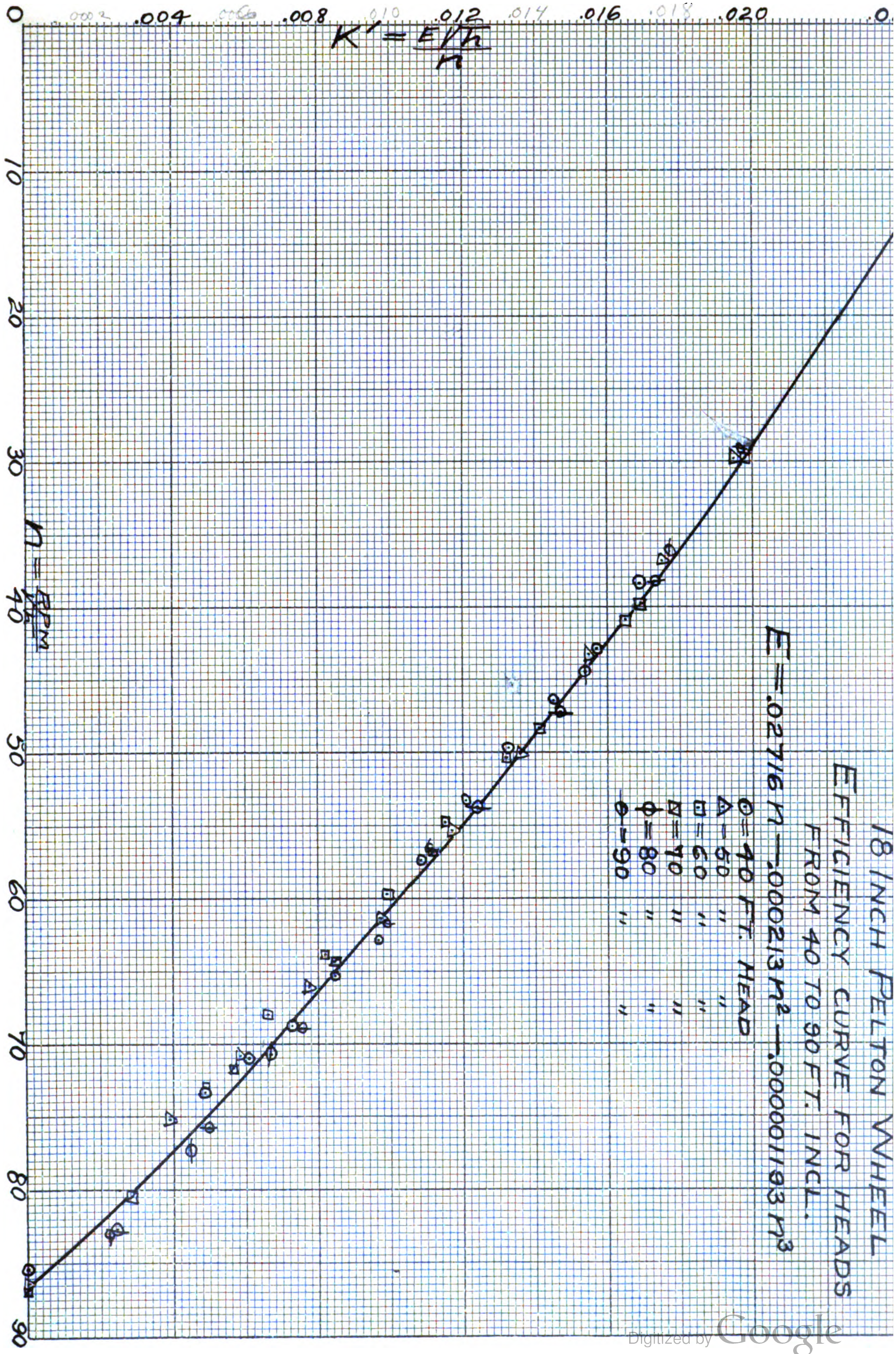
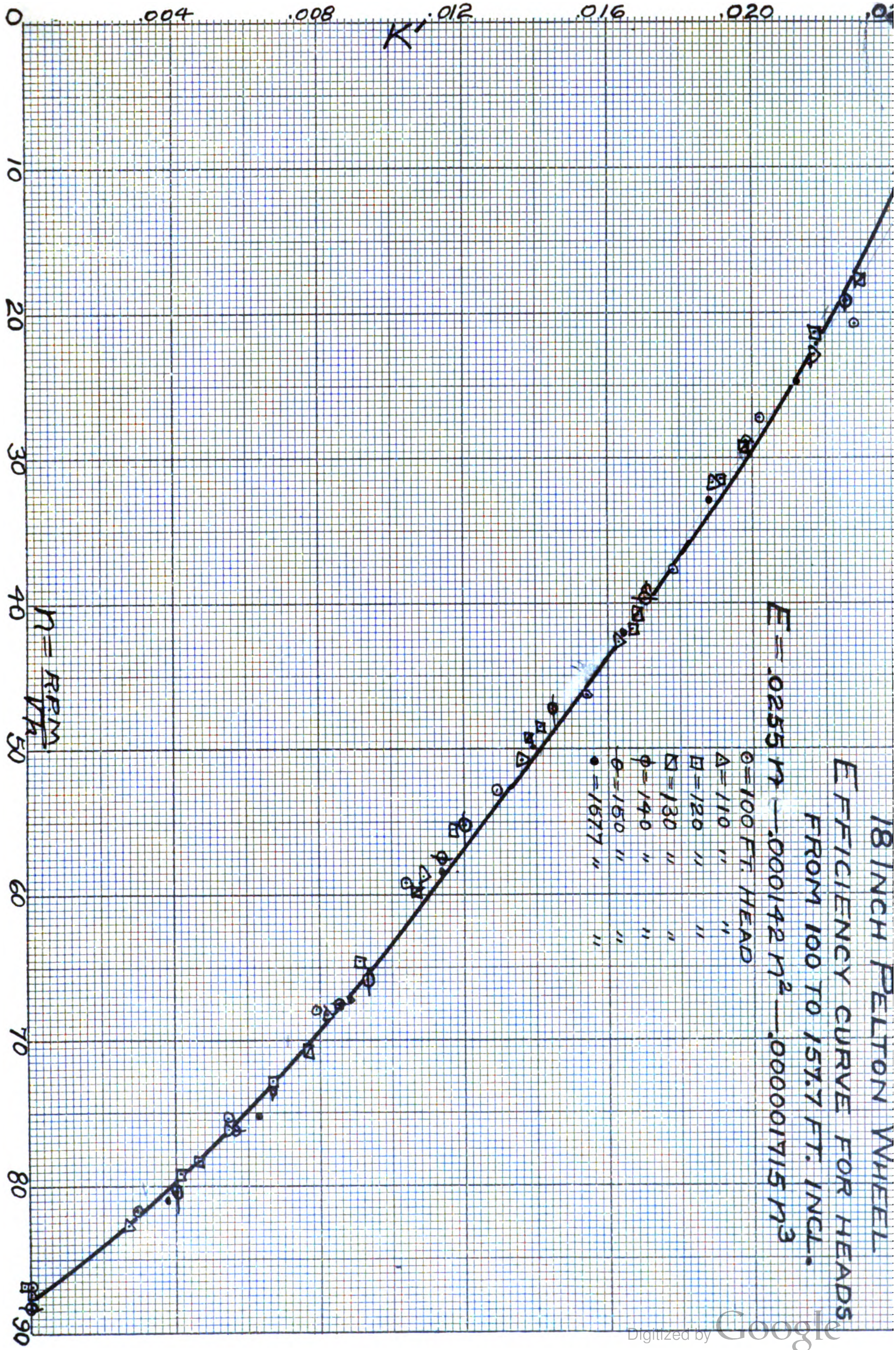
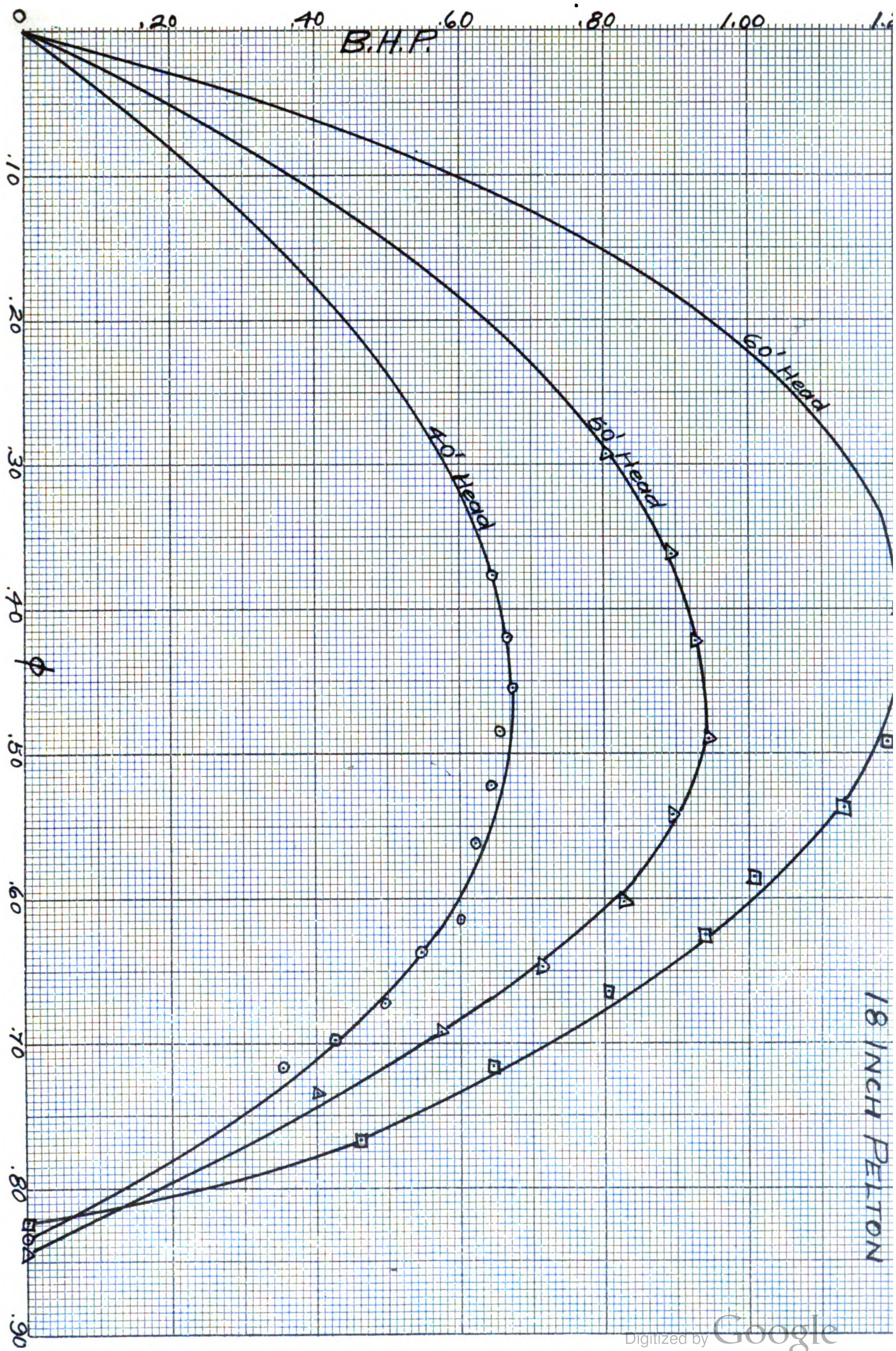
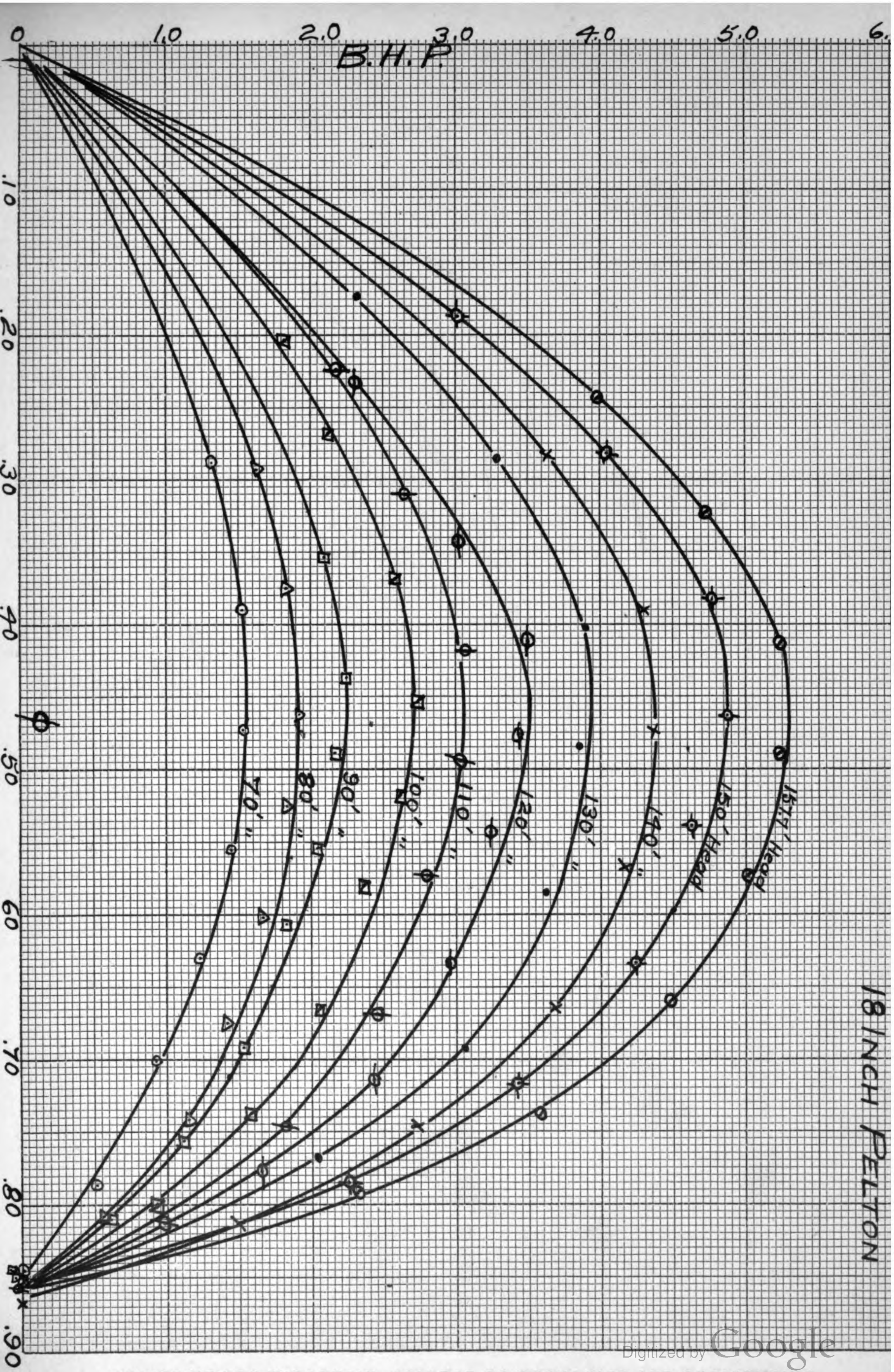

18 INCH PELTON WHEEL
EFFICIENCY CURVE FOR HEADS
FROM 40 TO 90 FT. INCL.
E = .02716 n − .000213 n² − .000001193 n³
○ = 40 FT. HEAD
△ = 50 "
⊡ = 60 "
▽ = 70 "
ϕ = 80 "
-o- = 90 "
K' = E/√h / n
0
.002
.004
.006
.008
.010
.012
.014
.016
.018
.020
n = RPM/√h
10
20
30
40
50
60
70
80
90


18 INCH PELTON WHEEL
EFFICIENCY CURVE FOR HEADS
FROM 100 TO 157.7 FT. INCL.
E = .0255 n − .000142 n² − .00000175 n³
⊙ = 100 FT. HEAD
Δ = 110 "
⊡ = 120 "
⊠ = 130 "
φ = 140 "
θ = 150 "
● = 1577 "
K'
0
.004
.008
.012
.016
.020
.024
10
20
30
40
50
60
70
80
90
n = RPM/√h


B.H.P.
0
.20
.40
.60
.80
1.00
1.2
.10
.20
.30
.40
φ
.50
.60
.70
.80
.90
60' Head
50' Head
40' Head
18 INCH PELTON



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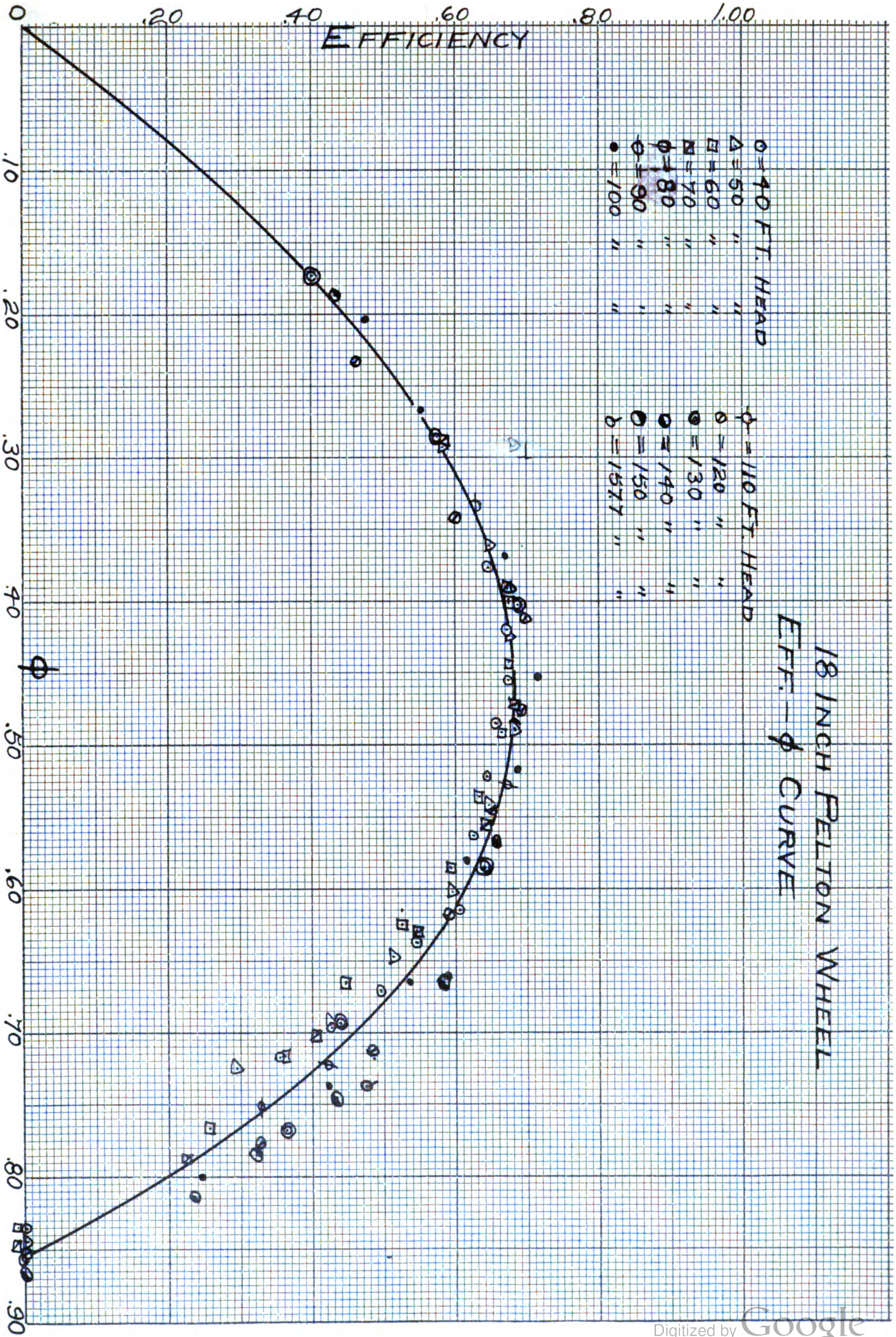

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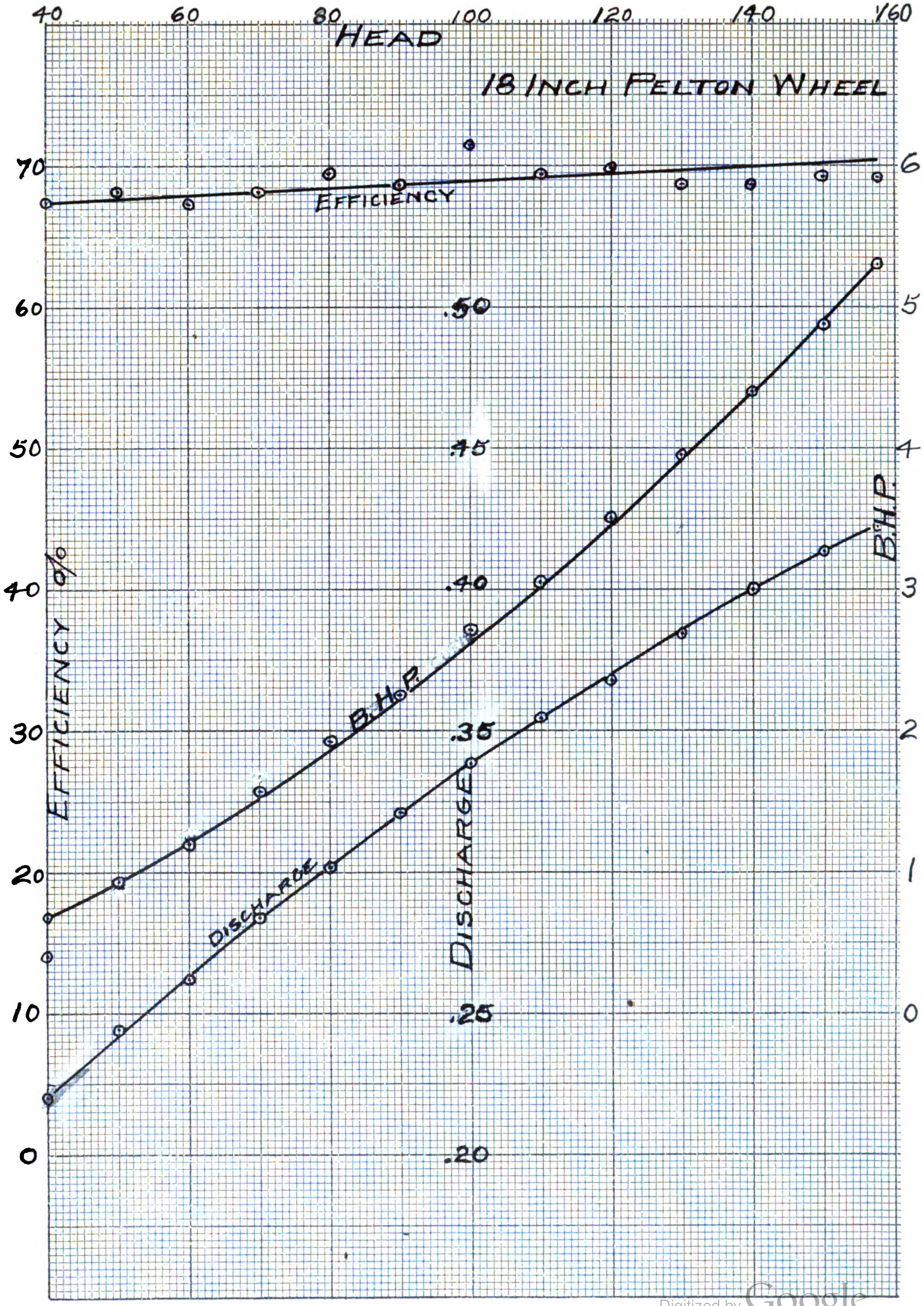

HEAD
40
60
80
100
120
140
160
18 INCH PELTON WHEEL
EFFICIENCY
B.H.P.
DISCHARGE
EFFICIENCY %
DISCHARGE
B.H.P.
70
60
50
40
30
20
10
0
.50
.45
.40
.35
.25
.20
6
5
4
3
2
1
0

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